Subjective Assessment of Indoor Air Quality in Office Buildings

by

Ali Saeed Al-Qahtani

A Thesis Presented to the

FACULTY OF THE COLLEGE OF GRADUATE STUDIES

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This thesis, written by ALI SAEED AL-QAHTANI under the direction of his Thesis Advisor and approved by his Thesis Committee, has been presented to and accepted by the Dean of College of Graduate Studies, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE IN ARCHITECTURAL ENGINEERING.**

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كلية الدراسات العليا

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This thesis is dedicated to my beloved parents and family for their continuous support.

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خلاصة الرسالة

إسم الطالب : علي سعيد علي القحطاني
عنوان الرسالة : تقييم موضوعي لجودة الهواء الداخلي فى المباني المكتبية
التخصص: هندسة معمارية
تاريخ الشهادة : ١٤١٤/١/٢٠ هـ

تناقش هذه الرسالة المشاكل الناتجة من انخفاض جودة الهواء الداخلي فى المباني والتى ثبت أن لها تأثير سلبي على مستخدمي المباني . وقد تم تحديد نوعين من المشاكل المتعلقة بجودة الهواء الداخلي . النوع الأول المشاكل التى يعانيها المستخدمين من جراء انخفاض جودة الهواء الداخلي والتى تسبب أعراض مرضية للمستخدم وتخفض انتاجيته . والنوع الثاني المشاكل المتعلقة بأنظمة المباني والتي قد تؤدي الى إنخفاض جودة الهواء الداخلي .

وقد قام الباحث بإجراء مسح استبياني شمل ٣٠ مبنى مكتبي فى المنطقة الشرقية . ويتكون الإستبيان من جزأين , يبحث الجزء الأول على تقييم المستخدمين للبيئة الداخلية بشكل عام وجودة الهواء بشكل خاص وقد تم جمع ٨٤٦ استبيان من مستخدمي المباني لهذا الغرض. أما الجزء الثاني فيركز على أنظمة المباني ومدى تأثيرها على جودة الهواء الداخلي وقد تم جمع ٣٠ استبيان من كل مبني لجمع المعلومات عن أنظمة المباني .

وقد تم الإستعانة ببرنامج احصاء لتحليل الإستبيانات وتبين من نتائج التحليل انخفاض جودة الهواء الداخلي فى بعض المباني التي شملها المسح الإستبياني وان لذلك تأثيرا سلبيا على صحة وانتاجية المستخدمين . وتبين كذلك ان مواد البناء وأنظمة تكييف ومعالجة الهواء فى المبنى لها دور كبير فى التأثير على جودة الهواء الداخلي .

درجة الماجستير فى العلوم

جامعة الملك فهد للبترول والمعادن
الظهران , المملكة العربية السعودية
التاريخ : ١٤١٤/١/٢٠ هـ

THESIS ABSTRACT

NAME OF STUDENT: ALI SAEED AL-QAHTANTY

TITLE OF THE STUDY: SUBJECTIVE ASSESSMENT OF INDOOR AIR QUALITY IN OFFICE BUILDINGS

MAJOR FIELD : ARCHITECTURAL ENGINEERING

DATE OF DEGREE : JULY, 1993

Indoor Air Quality (IAQ) in modern buildings has become a major concern for building designers, owners, and managers due to its adverse effect on occupants' health and productivity. This thesis discusses the Indoor Air Quality problems in Saudi office buildings. To identify these problems a sample survey of thirty buildings was undertaken.

The survey includes two main parts: Occupant's survey and Building survey. The first is for identifying the IAQ problems related to the occupants. The second is for identifying the IAQ problems related to building systems. Thirty buildings in the Eastern Province, were surveyed. 846 occupants' questionnaires and 30 buildings' questionnaires were collected. Both of these surveys were analyzed by a statistical computer program called SPSS.

It has been revealed by this survey, that some buildings have a low Indoor Air Quality, which has a negative effect on occupants health and productivity. Also it was found that the building envelop, the HVAC system , and the type of air handling system in the building could have a leading roll in reducing the IAQ

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CHAPTER 1: INTRODUCTION

1.1 Background:

Struggle with the outdoor natural environment has been one of the major problems facing humanity since its early history. This struggle has been revolving around the protection of man and his assets from the elements of the environment. It started with using naturally available shelters such as caves, going through trial and error of using available materials around him, and finally building high tech homes in order to protect human indoor life from the outdoors. As building technology advanced, this protection became more efficient and the indoor environment came under control.

Modern man spends about 85-90% of his time in a mechanically controlled environment. Most buildings are kept very tight to keep away dust and unconditioned air. Fresh air supply is kept to a minimum and re-circulated air is used intensively to save energy. All of these factors plus the use of new construction materials and chemicals, office equipment, and smoking has generated a new struggle for man: the problem of high level of indoor contaminants, which is commonly known as the Indoor Air Quality (IAQ) problem.

The low quality of indoor air has adverse effects on people working in the indoor environment. Various symptoms of headaches, dizziness, nausea, fatigue and dry skin have been experienced by occupants during their stay in some indoor environments. Most of these symptoms disappear after leaving the work place. After many complaints, the problem surfaced and buildings where these symptoms had been experienced were called Sick Buildings. A building can be diagnosed as a sick building if 20 % or more of its occupants exhibit one or more of the above mentioned symptoms for two weeks and such symptoms disappear when leaving the building. Another term is also used to refer to these symptoms, Sick Building Syndrome (SBS), which is defined as " a set of varied symptoms experienced by people working in predominantly air conditioned buildings"(Hansen,1991). When these symptoms develop into a serious illness, it is then called a Building Related Illness (BRI).

Occupants with these kinds of symptoms or illnesses will not only feel uncomfortable in the indoor environment, but may also have low productivity. This has led tenants to leave buildings. Building owners have lost business, besides having legal problems in the courts for not providing healthy indoor environments. Such problems have directed international public attention to indoor air quality issues.

In the United States and other industrial nations, people have been concerned with IAQ at all levels, because they have suffered immensely from the outdoor pollution and they do not want to repeat the same mistakes and ending up fighting the same battle indoors. The public awareness in these countries was triggered by the effort of professional societies such as the National Institute Occupational Safety and Health (NIOSH)and the American Society of Heating, Refrigeration, and Air-conditioning (ASHRAE).

This public awareness about IAQ and its effect on health transformed the occupants' complaints into legal cases in courts. Owners, facility managers and HVAC designers were held liable for an occupants' discomfort and/or illness caused by the indoor environment.

1.2 Statement of the Problem:

Since the discovery of oil in the Kingdom, we have been living in modern buildings that rely 100% on electrically operated air-conditioning systems. These systems vary from simple window type units mostly used for residential applications, to central systems for commercial and public buildings. Additionally the outdoor ambient temperatures in the summer months reach 115 F. All of these factors contributed to building tight buildings that don't allow dust and outdoor air to enter without control.

We also use the same building materials, detergents, and equipment as the Americans, and the Europeans, our building maintenance activities are below their standard. All of these factors raise the following questions :

1- Do we have IAQ problems in our buildings?

2- What is the nature of these problems?

3- How could we overcome these problems?

Throughout this thesis, the writer will try to find answers to these questions.

1.3 Significance of the study:

Indoor environment in general and IAQ issues in particular, have not been a prime concern for research in the Kingdom of Saudi Arabia. This is proven by the unavailability of literature on IAQ in the Kingdom. Most of the available literature on Air Quality is concerned with outdoor environmental pollution. This study would be the first study in the Kingdom that deals with IAQ problems. This hopefully would pin point potential areas for further research in indoor environment .

1.4 Objectives:

The main objectives of this research are:

1- Identifying the problems associated with IAQ,

2- Assessment of the contribution of the building design on IAQ,

3- Assessment of the contribution of the operation and maintenance on IAQ,

4- Assessment of the occupants response to IAQ, and

5- Assessment of the possible existence of IAQ problems in Saudi office buildings

1.5 Scope and Limitations:

The scope of this research will be limited to studying IAQ problems in a selected group of buildings in the Eastern Province of the Kingdom . The study will be on IAQ in multi-story office buildings only due to the ease of access to occupants, and the information about the building. The study is limited to office buildings in DAMMAM and KHOBAR cities. Office buildings that depend on central HVAC system for controlling the indoor environment and buildings with a tight envelop will be selected for study, because the indoor environment in such buildings could be considered a true "Indoor Environment". The list of buildings that are going to be studied in this research are presented in Appendix A . All of these buildings were selected to fit the scope and limitations of this research.

CHAPTER 2: LITERATURE REVIEW

Throughout this chapter the main topics of the relevant indoor air quality literature will be discussed. Building systems that affect indoor air quality will be the first to be included. Indoor air pollutants are of a major concern due to their negative role in indoor air quality; therefore they will be discussed with regard to their chemical composition, sources, and the general factors that affect their behavior. Monitoring and modeling of indoor air quality are also part of this chapter ,due to their growing importance in diagnosing and predicting indoor air quality.

2.1 Building systems & IAQ:

The building design team has to design the indoor environment to be aesthetically acceptable, to provide thermal comfort, and to insure that the indoor environment has adequate natural and artificial lighting and acoustic systems that match the building use. With the addition of new building materials and the growth of public awareness, it became a new requirement that a building designer should guarantee proper indoor air quality. Below are discussions of the impact of building systems, mainly architectural systems and HVAC systems, which affect indoor air quality.

2.1.1 Architectural System:

Architects play a leading role in building design. Architectural design transforms owner and user requirements or developer plans and criteria into building layouts. Building aesthetics, cost, site limitations, outdoor and indoor environment considerations are some examples of relevant criteria. Providing a healthy indoor environment is not usually considered as a design criterion unless dictated by the building function (e.g in hospitals)(O'Sullivan,1988). Such an attitude is natural because " the design professionals have concentrated quite naturally on the recent and on going changes to the Building Fire and Safety Regulations. This resulted in a too narrow concern with *efficiency and safety*, such that the traditional concept , and the Healthy Building has been lost"(O'Sullivan,1988) . In this section some aspects of architectural design that have direct influence on indoor air quality are discussed.

2.1.1.1 Building Envelope:

A building envelop is defined as the barrier that separates the indoor environment from the outdoor . It acts as a shield to protect the indoor environment from outdoor elements and keeps the indoor environment under control. Architecturally, the building envelope plays a very important role in defining building shape because it is the only part of the building that is seen from the outside. The tightness of the building envelope is the only part that concerns us due to its effect on indoor environment in general and indoor air quality in particular.

The building envelope used to act mainly as a structural element to hold building load and wind load. With the development of new structural systems this function vanished and the building envelope now acts as a non-structural element that separates the indoor environment from the outdoor. As energy efficiency has became a very important design parameter, tight envelopes have become necessary.

The building envelope is designed to be tight for the following reasons:

1. Damage to the envelope from condensation effects of the air borne convection flow of moisture can be minimized.
2. Energy consumption can be reduced by limiting the amount of both sensible and latent heat that must be provided to temper the incoming air
3. Heat recovery devices can be used effectively on the ventilation air.
4. Noise transmission through the envelope can be reduced. (Dumout,1988)

The envelope could be insured tight by building materials with low air leaks. Door and window tightness play an important role in tightening the envelope because these components are the weakest points in the building envelop. Providing door and windows with weather stripping will increase their efficiency in tightening the envelope.

2.1.1.2 Interior Building Material & Furnishing:

Selection of interior building materials, such as floor finish, wall finish and partition systems, to provide the desired indoor spatial and environmental requirement is one of the prime concerns of architects. Studies conducted by the World Health Organization (WHO) in several industrialized countries concluded that the primary emission sources of Volatile Organic Compounds (VOC's) exist inside the buildings (Berglund,1988). These chemicals were traced and found to be emitted from building materials and furnishings. Formaldehyde is an example of an indoor pollutant that is emitted from foam insulation and plywood. Formaldehyde emission from some building materials measured in test chamber are listed in Table 1 (Gustafsson,1988).

The emission rate of pollutants from interior building materials is dependent on temperature and humidity. The formaldehyde emission rate is doubled for each 7 deg. rise in temperature. It is also doubled with relative humidity increase from 30% to 70% at 22 deg. C (Nielsen,1988). Aging of material is another factor to consider. The emission rate of organic compounds from new materials as a function of time was studied and results showed that "high emission rates were found during the first 100 days; after 40-80 days the concentrations had decreased to half their initial values" (Berglund,1988).

Building design professionals can only select building materials from the available materials in the market provided by material producers. However, by applying strict material selection criteria that take pollutant emission in consideration, they can influence the production specification of these materials.

Table 1: Formaldehyde emission from parquet floor and decorative paneling (Gustafsson,1988)

Test object	Concentration (ppm	Remarks
Parquet floor I	0.11	
Parquet floor II	0.02	
Decorative Paneling	1.0	Lauan-type
Decorative Paneling	0.7	coated with paper

2.1.1.3 Building Moisture Control:

Moisture control is an important aspect of building design due to the severe damage it causes. Moisture accelerates the decomposition of building materials causing the release of pollutants. It also it accelerates the aging of material and reduces its life. Most importantly, the presence of moisture provides the best environment for microbes, fungi and other biological pollutants.

Building water leaks, rain, ground water, and condensation are the main sources of moisture in buildings. Moisture resulting from these sources could be overcome by following these guidelines:

1- Pipes for water, sewage, and fire protection should be designed as accessible as possible. This will make it easy to detect and repair water leaks.

2- Impermeable materials should be considered for the building envelope. Moisture protection layers should be used in areas with high probability of moisture collection such as roofs and to protect materials with low permeability.

3- Ground and surface water drainage should be provided around building foundation and exterior walls.

4- Condensation can be avoided by the proper use of ventilation air. Air condenses on roof, and wall surfaces and cavities due to the temperature deferential between these components and air. Ventilating roof and walls surfaces and cavities by insuring air flow through, will reduce the possibility of condensation and will dry moisture when it happens. Ventilation could be achieved by convection or forced ventilation by means of fans.(Samuelson,1988)

2.1.1.4 Indoor Volume:

Building dimensions are determined by the architect according to building function, the desired esthetic values, structural limitations, and economical constraints. Occupied-zone volume is part of these dimensions and has an important role in indoor air quality. Higher indoor volume means lower concentration of indoor pollutants. Building codes have set the minimum dimensions for rooms to ensure that room volume will not be reduced in a desire to reduce building area and hence cost. Table 2 demonstrates some of these codes in different European countries.

Table 2: Requirements on room height and floor area for the smallest room in different European countries building codes (Gustafsson,1988)

Country	Room height, m	Room area, m^2	References
Austria*	2,50/2,60	9/10	(25-30)
Belgium	2,30	6,5	(31)
Czechoslovakia	2,50	8	(32)
Denmark	2,30	7	(33)
Finland	2,40	7	(34)
France	2,50	7	(35-37)
F.R. Germany*	2,30/2,40	6/8/10	(38-45)
Iceland	2,40	7	(46)
Ireland	2,40	6,5	(47)
Italy	2,70	9	(48)
Netherlands	2,40	6	(49)
Norway	2,40	6,25**	(50)
Poland	2,50	8	(51)
Sweden	2,40	7	(52)
Switzerland*	no req.	no req.	(53)
Turkey	2,40	no req.	(54)
United Kingdom*	no req.	no req.	(55)
Yugoslavia	2,50	6	(56)

*) Different regulations on regional level.
**) Indirect requirement

2.1.2 HVAC System :

Modern buildings depend on mechanically operated systems for controlling indoor environment. These systems are usually referred to as Heating, Ventilation, and Air-Conditioning systems (HVAC systems).

HVAC systems have a direct influence on indoor environment because they perform the following tasks:

- Cool air and /or heat air

- Distribute Air
- Humidify & Dehumidify Air
- Exchange Indoor Air
- Clean Air

HVAC systems range from simple unitary systems to complex multi-unit central systems. Basically, all these systems perform the above mentioned tasks with varying complexity depending on the application. The last two tasks, exchanging indoor air and cleaning air, are the most important tasks as far as IAQ is concerned.

The Indoor Air Exchange rate is the rate at which the HVAC system exhausts used indoor air and replace it with "fresh" out door air. The exhaust outlets are usually placed in zones with the highest probable contamination such as toilets, kitchens, labs et. The introduction of outdoor air is for two main purposes:(1) to create a pressure differential and hence avoid infiltration of outdoor air, and (2) to dilute pollutants and reduce their concentrations. Higher fresh air quantities mean better IAQ, but energy consumption constraints limit the amount of outdoor air. HVAC systems consume less energy when processing re-circulated air due to its low temperature. The struggle to design energy efficient buildings has made HVAC designers use low exchange rates that have resulted in IAQ problems. This practice required professional societies such as ASHRAE to step in and provide guidelines and standards for ventilation rates.

2.1.2.1 Ventilation Standards:

American Society of Heating Refrigeration, and Air-conditioning Engineers (ASHRAE) is one of the leading professional bodies worldwide in the area of HVAC standardization. Ventilation standards have been their concern since 1820. Figure 1 illustrates the ventilation rate standard adopted by ASHRAE over the period 1820-1981. It demonstrates clearly the conflict between higher ventilation rates and energy consumption. In the early days of the 1800's the main purpose of ventilation was offsetting indoor activities that generated pollutants (personal wastes, coal burning, and gas light pollutants). Energy conservation was not an issue at that time.

During the 1970's and because of the energy crises, the demand for energy conservation was high. In the building industry, ventilation rates were reconsidered in order to improve building energy efficiency. The lowest ventilation rate was 5 cubic feet per minute per person (5 CFM/Person). This rate was used in designing new buildings and even old buildings were retrofitted to follow this standard.

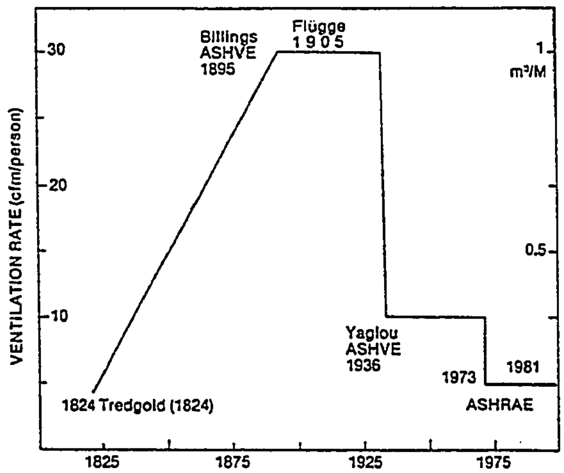


Figure 1: Ventilation Standard from 1820 -1981 (Meyer, 1983)

Buildings became energy efficient; however, that was not without price. Low ventilation rates, tighter building envelopes, and the existence of indoor contaminants resulted in low indoor air quality and the sick building syndrome appeared. In response to this problem, ASHRAE elevated ventilation rates to a minimum value of 15 CFM/person or as illustrated in Table 3. The latest revision of ventilation standard by ASHRAE is called " Ventilation for Acceptable Indoor Air Quality".

Table 3: ASHRAE 62-1989-Outdoor air requirements for ventilation

Application	Estimated Maximum Occupancy P/1000 ft^2 or 100 m^2	Outdoor Air Requirements cfm/ person	cfm/ft^2	Comments
Garages, Repair, Service Stations				
Enclosed parking garage			1.50	Distribution among people must consider worker location and concentration of running engines; stands where engines are run must incorporate systems for positive engine exhaust withdrawal. Contaminant sensors may be used to control ventilation.
Auto repair rooms			1.50	
Hotels, Motels, Resorts, Dormitories			cfm/room	
Bedrooms			30	
Living rooms			30	
Baths			35	Installed capacity for intermittent use.
Lobbies	30	15		
Conference rooms	50	20		
Assembly rooms	120	15		
Dormitory sleeping areas	20	15		See also food and beverage services, merchandising, barber and beauty shops, garages.
Gambling casinos	120	30		Supplementary smoke-removal equipment may be required.

Acceptable Indoor Quality is defined by ASHRAE in their ventilation standard as " air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction" (ASHRAE standard 62-1989). If this definition is not true for a particular building , the building is considered a "***sick building***".

HVAC systems, like any other building systems go through design, construction, operation and maintenance. Throughout the remainder of this section, these stages will be discussed for HVAC systems with regard to their effect on indoor air quality.

2.1.2.2 Design:

Traditionally, HVAC design engineers consider the following criteria in design:

1.Economics

- First Cost
- Running Cost (energy and maintenance cost)

2. Indoor environment

3. System integration with other building systems

The weight of each of these criteria differs from one project to another; however, the system's first cost, its capacity, and its energy cost are the most important factors. This is mainly due to their direct effect on the project budget and on system performance. It was not until recently that indoor air quality has become a very important criterion. This was found out when award winning buildings (concerning energy efficiency and initial cost) were classified as sick buildings and were left empty by tenants.

A Honeywell company Indoor Air Quality Diagnostic Team found that " design related problems are second only to operation and maintenance in contributing to indoor air pollution"(Hansen,1991). These problems were mainly in ventilation and air distribution, inadequate filtration; and maintenance accessibility. This is because there is a direct relation between design decisions and these aspects of HVAC design.

Indoor Air Quality is a subjective issue that cannot be easily quantified during the building design stage. Providing healthier indoor environments conflicts with first cost and energy cost design criteria. Due to this reason and the subjective nature of the IAQ issue, designers tend to override IAQ to save initial cost and energy cost.

Providing ventilation air in the right quantities would not necessarily insure a good indoor environment in absence of a proper distribution system. HVAC systems with "short circuited " air flow patterns (when the outdoor air inlet is located near the exhaust outlet) can have IAQ problems (Hansen,1991).

One of the important aspects of HVAC design related to IAQ is the selection of filters for removing dust, fibrous particles, and other suspended pollutants in the air stream. Panel filters, renewable media filters, and electronic air cleaners are the common types of air filters that are heavily used in HVAC systems. Selecting the proper filter type for the building application is very essential for IAQ. Buildings with poor filtration systems would have accumulated dust inside, which would result in damage to building furniture, increase in custodial service costs, and could cause occupant heath problems.

The HVAC designer is also responsible for providing maintenance accessibility for maintenance personnel and their equipment. Without this access maintenance for HVAC systems would be reduced or in the worst cases would not be possible. The Honeywell IAQ diagnostic team found out that reduced or missing maintenance activity is the leading cause for most IAQ problems. The relevance of operation & maintenance to IAQ will be addressed later in more detail.

2.1.2.3 Construction:

During the construction process of HVAC systems, contractors should follow the working drawings produced by the designer and there should be no IAQ relation between construction and IAQ. However, this is not always true. In many occasions, equipment specified by the designers could not be found in the market, or the contractor wanted to use a different system to save money . In both cases if no proper coordination exists between construction consultant, designer, and contractor, the system will not perform as expected.

An example of this is when a contractor changes the type of air filter from an expensive efficient filter to a cheaper and less efficient filter. Also it is common for contractors to leave out some component intentionally or unintentionally such as dampers, and controls. Therefore, close attention by the construction consultant is required.

Another case where a construction process affects indoor air quality, is the cleanliness of the HVAC system. The contractor should insure that the HVAC system's components are clean and free from dirt and construction debris, especially those components that are not accessible at later stages such as duct runs. It is not uncommon to find papers, empty soft drinks cans, or pieces of duct insulation scattered throughout duct runs (Meckler,1991).

Finally, the last step in the construction process and the most important one related to IAQ, is commissioning the HVAC system . It is defined as " procedures and methods for *verifying* and *documenting* the performance of HVAC systems to ensure proper operation according to the original or re configured design entente" (Mackler,1991).

Verifying means to checking the system's flows and ratings and making sure that they are within the design limitations. Testing, Adjusting, and Balancing are the common terms for this process. This process includes the following :

1- Balancing air and water distribution by proportioning flows within the distribution system (submains, branches, and terminals according to specified design quantities),

2- Adjusting the total system flows by regulating the specified fluid flow rate and air flow patterns at the terminal equipment (reduce fan speed, adjust damper setting), and

3- Testing, which is performed throughout the previous steps to find out the system's testing and balanceing air volume readings .

This process insures that the contractor has installed the HVAC system according to owner and designer intent. It is usually performed by an independent Testing and Balancing consultant who works on the behalf of the owner.

This process will reduce or eliminate construction flaws by the contractors and reduce or eliminate the above mentioned construction related IAQ problems. Also it will give the designer the ability to check his design and make the necessary changes as required.

The documentation part of the commissioning is responsible for documenting the previous process of Testing, Adjusting , and Balancing for the record. Also it should be responsible for describing the installed HVAC system and its intended operational modes, performance goals , and Operation & Maintenance instructions. This documentation will facilitate the operation and maintenance of the system that is very critical to IAQ as will be indicated later.

Training of operation and maintenance personnel is normally performed as part of the commissioning process. Maintenance personnel usually get involved in the details of the system and miss the over all picture of the system and how its components relate to each other. By conveying to them the design intent of the designer and the overall schematics of the system, and training them on how to maintain the system according to manufacturer recommendation, the process of taking care of the system would be done without jeopardizing their system's maintenance and hence IAQ. Also maintenance personnel should be informed not to perform any systems modification without consulting the designer, because this might deviate the system operation from the design intent.

2.1.2.4 Operation and Maintenance (O & M) :

An HVAC system is a dynamic system that requires operation of its components and consequently maintenance. Below are some of the O & M aspects related to IAQ

Operation modes of HVAC are set by the designer according to the design criteria specified by the owner; however, these modes are not rigid. They have modification limits that a building manager could work with as a response to change in some building functions or schedule of operation. In a newly occupied building, building managers could allow higher outdoor air (up to 100%) before tenant use of the building. In order to exhaust indoor pollutants emitted from building material and furnishing. Also the HVAC system should be scheduled to start before occupants use the building in the morning with higher outdoor air for thermal comfort and dilution or exhaust of any indoor pollutant that accumulated over night (Meckler,1991).

Response of occupants to the indoor environment should be monitored and the HVAC system's adjustment should be altered accordingly within specified limits by the HVAC designer. Odors and accumulation of indoor pollutants in certain areas of the facility should be attended by removing the source, providing a local exhaust, and/or increasing outdoor air. Users' activities should be monitored to prohibit generation of pollutants in areas that have no provisions to compensate for the pollutants. An example of this nature is smoking, which should not be allowed in areas with no provision for smoking in the original design. (Daisey,1991)

Maintenance of HVAC equipment is twofolds. The first is cleaning of system components. Dust, biological contaminants, and other indoor contaminates accumulate on an HVAC system's components such as its air cleaning devices, coils and its drain pans, ducts, fan blades, and terminal devices. If these components are not cleaned regularly, they could become sources for indoor contaminants and jeopardize IAQ. Second is the corrective and preventive maintenance of the equipment.

A faulty fresh air damper would reduce the amount of fresh air introduced into the building, a malfunctioning exhaust fan in a kitchen would result in the spread of cooking odors and smoke in the building, and a fresh air intake clogged by a bird nest would reduce fresh air intake. All of these are examples of the effect of corrective and preventive maintenance on IAQ. (Meckler,1991) (Hansen,1991)

2.2 Indoor Air Pollutants:

Indoor air pollutants are the prime concern of any Indoor Air Quality study; therefore, this chapter will be devoted to Indoor Air Pollutants with regard to their chemical, and physical properties and the sources that generate them outdoors and indoors. Indoor pollutants are controlled by many factors affecting their indoor concentrations. These factors will be discussed to understand the variables that control indoor pollutant concentrations, which would help in developing Indoor Air Quality models at a later stage.

2.2.1 Carbon Monoxide:

Carbon Monoxide (CO) is an inert gas that does not react with other gases or substances under normal atmospheric conditions. CO is available in the outside environment in varying concentrations . Areas with heavy industry or with congested traffic have higher concentrations of this gas than other areas .

The main effect of CO on human health lies in its affinity for hemoglobin in blood. Carbon Monoxide is 200-250 times more efficient at hemoglobin binding than Oxygen. This could lead to a considerable reduction in Oxygen carrying capacity and subsequently leads to serious illness or death.

Indoor concentrations of Carbon Monoxide are often higher than those outdoors, due to the available indoor sources. Gas cooking is considered one of the common indoor sources for CO (among many others) especially in residential buildings. " Emission from gas fired stoves, ovens, and heaters were found to be in the range of 315-1040 μg/Kcal for top burners and 530 to 1620 μg/Kcal for ovens". Tobacco smoke is another source of CO. It produces 130 μg of CO per 1 mg of smoked tobacco.(Yocom,1982)

2.2.2 Carbon Dioxide:

Carbon Dioxide (CO_2) exists in the outdoor natural environment with an average concentration of 400 ppm. However , the indoor concentrations are often more than those out doors. In a survey made for residential buildings, it has been found that the indoor concentration of CO_2 exceeds the outdoor in 90% of the houses. (Yocom,1982)

The human body is the main source of CO_2 in the indoor environment. The human body dissipates an average of 200 ml/day. This amount of Carbon Dioxide is a function of food composition and the activity level of the body.

Carbon Dioxide is not usually considered as an outdoor pollutant. However, later studies on the effect of CO_2 on the human health in closed environments show that " exposure of healthy individuals for prolonged periods of 1.5% CO apparently cause mild metabolic stress while exposure to 7-10% will produce unconsciousness within a few minutes". Also, it has been proved that exposure to 0.7-1.0% CO_2 results in an increase in respiratory volume and cyclic changes in the acid-base balance in blood. (Wadden,1983)

2.2.3 Nitrogen Dioxide:

Nitrogen Dioxide is formed in the outdoor atmosphere by the reaction of Nitric Oxide (NO) with the Oxygen and Ozone. Nitric Oxide is generated outdoors by the composition process. Nitric Oxide (NO) is not considered a pollutant. However, due to the above mentioned reaction it is considered as a pollutant generator.

NO_2 has adverse effects on human health such as chronic lung disease when concentration is between 4-28%(Yocom,1982). In a British survey among school children, it was found that a " high percentage of students, living in houses with gas stoves, suffer from reduced respiratory function".(Yocom,1982)

Gas cooking appliances, unvented heaters, and tobacco smoke are the major sources of Nitrogen Dioxide.

2.2.4 Sulfur Dioxide:

Sulfur Dioxide (SO_2)This gas is the most extensively studied pollutant in the outdoor environment, due to its negative effect on human health and its contribution in the forming of acid rain. Outdoor concentrations of SO_2 are usually higher than indoor. Indoor concentrations are typically below 20 ppb. (Yocom,1982)

One of the main characteristics of this pollutant is its reactivity. It tends to react with a wide spectrum of chemicals. Therefore indoor SO_2 reacts with building materials and gets absorbed by them. SO_2 fully mixes with air at all temperatures and dissolves in water.

The main indoor source of SO_2 is the coal burning; therefore, indoor concentration of SO_2 tends to be higher in winter than in summer due to the use of coal in winter for heating.

2.2.5 Formaldehyde:

Formaldehyde is the key substance for providing synthetic urea and phenol-formaldehyde resins. Such resins are mostly used in the production process of many building materials such as foam insulation, plywood, carpets, and particle board adhesives. Formaldehyde is released to the indoor environment from these building materials. The rate of diffusion of this pollutant is a function of temperature and humidity.

Most complaints of high concentrations of formaldehyde in indoor environments were from buildings with formaldehyde foam insulation and mobile homes with significant use of plywood paneling. (Wadden,1983)

Eye' irritation, and general irritations of the upper respiratory system are the initial symptoms of formaldehyde exposure in the range of 0.1 - 5 ppm. Also experiments on animals have resulted in cancer development.

2.2.6 Dust:

Dust is defined as " solid particles projected into the air by natural forces such as wind, volcanic eruptions, earthquakes, or by mechanical processes including crushing grinding, demolishing, blasting, drilling, screening, and sweeping". (ASHRAE Fundamentals,1991)

Dust immigrates into the indoor environment from the outside carried by the infiltrated air. The infiltrated air gets the indoors through cracks, unsealed windows and doors, and mainly through the ventilation system. Dust causes discomfort for people and damages home furniture and household equipment. Also it has some negative health effects on people with ultra-sensitive lungs specially infants and elderly people.

2.2.7 Fibrous Particles :

Mostly Asbestos and fiberglass would come under this heading, due to the appearance of their particles as fibers. Asbestos is a hydrated mineral silicate. It used to be a very common construction material. Most countries have banned the use of Asbestos, due to the reported high risk of lung cancer and respiratory disease caused by thetiny fibers (>5μm) released from bonded Asbestos. (Wadden,1983)

Fiberglass and rock fibers are mostly used as building insulation. Fiberglass particles range between 1μm-1.8μm in diameter. There is no significant proof so far linking fiberglass particle concentration with human health problems.

2.2.8 Ozone :

Ozone (O_3) is an extremely reactive pollutant that oxidizes most of the chemicals in nature. the outdoor concentration of ozone is much higher than the indoor concentrations. This is due to the production of O_3 in the outdoors as a result of the reaction caused by sunlight on Nitrogen Oxides and Hydro Carbons. Copy machines, laser printers, and electrostatic air cleaners are the main indoor sources of Ozone.(Yocom,1982) (Wadden,1983)

A high concentration of Ozone causes lung problems and malfunctioning respiratory systems in general. Table 4 shows the heath effect of different Ozone concentrations.

Table 4: Compilation of Results Reported in Human Studies Examining Ozone (Wadden,1983)

Concentration (ppm)	Exposure Duration (hours) (for Clinical Studies); Averaging Time (for Epidemiological Studies)	Pollutant Measured (O_3 = ozone; O_x = oxidant)	Reported Effects	References
0.01–0.30	Hourly average	O_3	Lung function parameters in about 25% of Japanese school children tested were significantly correlated with O_3 concentrations (over the range of 0.01–0.30 ppm) in the 2 hr prior to testing.	Kagawa and Toyama (1975); Kagawa et al. (1976)
0.03–0.30	Hourly average	O_x	Although significant correlation was observed between decreased athletic performance and O_x concentrations in the range of 0.03–0.30 ppm, the criteria document states that inspection of the data reveals no obvious relationship between performance and O_x values below 0.10–0.15 ppm.	Wayne et al. (1967)
0.10	2	O_3	Decreased O_2 pressure in arterialized blood, increased airway resistance observed using nonstandard measurement techniques.	von Nieding et al. (1976)
0.10–0.15	Probably daily maximum hourly average	O_x	Increased rates of respiratory symptoms and headache were reported by Japanese students on days when O_x concentrations exceeded 0.15 ppm as compared to days when O_x concentrations were less than 0.10 ppm.	Makino and Mizoguchi (1975)
0.15	1	O_3	Subjective symptoms of discomfort were observed by most subjects, and discernible but not statistically significant changes in respiratory patterns occurred while performing vigorous exercise.	DeLucia and Adams (1977)
0.20	3	O_3	Reduction in visual acuity (night vision) observed.	Lagerwerff (1963)
0.20–0.25	2	O_3	Asthmatic patients exposed under intermittent, light exercise conditions showed no statistically significant changes in respiratory function. Symptom scores increased slightly during O_3 exposures. Small but statistically significant blood biochemical changes occurred.	Linn et al. (1978)

2.2.9 Odors:

Indoor odors are generated by occupants and their activities. The normal human body dissipates around 200 chemicals that are responsible for human body odors. Indoor activities such as cooking, smoking, and bath room use, generate odors with a variety of concentrations. (Meyer,1983)

Odors in general do not impose a major health threat for occupants; however, they do cause discomfort. Indoor odors could act as a signal that can be sensed by human for poor indoor air quality.

2.2.10 Microbes:

Bacteria, viruses, molds, fungi, and pollen are covered here as Microbes. Humans, animals, and plants are the sources of microbes. Microbes can be found anywhere these sources are available. (Meyer,1993)

The indoor environment has more microbe concentration than the outdoor in normal circumstances, due to tightness of the building and the availability of sources. Indoor air is usually the medium that transports microbes throughout the building. Water closets, dishwashers, air-conditioning systems and wall-to-wall carpeting act as breeding sites for many types of microbes.

The heath effect of microbes differs depending on the type of microbes. Some kinds of bacteria are harmless and help the human digestive system and many others are deadly.

2.2.11 Tobacco Smoke:

Tobacco smoke is the most dangerous indoor pollutant due to its toxic chemical compounds. Table 5 illustrates the basic constituents of tobacco smoke. The main sources of tobacco smoke are cigarettes, cigars, and pipes that are used by users in the indoor environment . The health effect of tobacco smoke on smokers has been heavily documented and is beyond the scope of this research. Lately, the concept of ***passive smoking*** is taking the lead. Passive smoking is defined as the involuntary smoking or the inhaling (by nonsmokers) of the second hand smoke dissipated by smokers. Occupants using the indoor environment are mostly non-smokers and are frequently exposed to passive smoking.

Many adverse health effects have been associated with passive smoking. "Children living in houses where parents smoked have been found to incur adverse pulmonary effects when compared to those from nonsmoking families" (Wadden,1983). A study of 90,000 nonsmoking Japanese woman proved that wives of heavy smokers have higher risk of developing lung cancer than those married to light or nonsmokers (Wadden,1983). In the United States, it has been reported by the Surgeon General that 4000 Americans die every year as a result of passive smoking (Meyer,1983).

Finally, Table 6 summarizes the health studies that have been made on passive smoking.

Table 5: Measurements of Constituents of Tobacco Smoke (Wadden,1983)

Constituent	Location	Ventilation, Air Changes Per Hour	Amount of Tobacco Burned	Concentration	Source[b]
		Experimental Conditions			
CO	80–170 m^3 rooms	6.4–2.3	46–101 cigarettes	4.5–75 ppm	1, 2
	Small car, 25 m^3 chamber	none	4–9	12–110 ppm	3, 4
Nicotine	57–80 m^3 rooms	6.4–8.2	42 cigarettes, 9 cigars	<0.1–0.42 mg/m^3	2, 1, 5
	38–170 m^3 rooms	none	10 cigarettes, 9 cigars	0.13–1.04 mg/m^3	2, 5
Total particulate matter	15–425 m^3 homes	1–3	7–35 cigarettes	1.1–3.0 mg/m^3	6, 7
	25 m^3 chamber	none	4–24 cigarettes	2.28–16.65 mg/m^3	3
Dimethylnitrosamine	4-m^3 box, 20 m^3 room	none	10–100 cigarettes	0.23–2.9 μg/m^3	8
Acrolein	30–170 m^3 rooms	none–2.4	5–150 cigarettes	0.02–0.20 ppm	5, 9
Acetaldehyde	38–170 m^3 rooms	none–2.4	5–150 cigarettes	0.06–0.56 ppm	5
Formaldehyde	30 m^3 box	none	5–10 cigarettes	0.23–0.46 ppm	9
NO	30 m^3 box	none	5–10 cigarettes	0.19–0.36 ppm	9
NO_2	30 m^3 box	none	5–10 cigarettes	0.02–0.04 ppm	9
		Natural Conditions			
CO	Office, restaurant club, tavern, arena	–	–	2.5–28 ppm	10, 11, 12, 13, 14
	submarine, boat, autos, bus, airplane	none–20	4–150 cigarettes	3–33 ppm	15, 16, 17, 18
Nicotine	submarine, terminal, restaurant	–	Up to 150 cigarettes	1–35 μg/m^3	15, 19
Total particulate matter	tavern, arena	none–6	–	0.15–0.98 mg/m^3	11, 12
Particles	house	–	1 cigar	48 × 10^6 particles/ft^3	20
Benzopyrene	arena	–	–	0.0071–0.021 μg/m^3	12, 21
Dimethylnitrosamine	bar	–	–	0.11–0.24 μg/m^3	8
Respirable particulate matter (RP)	restaurants, sports arena, bowling alley	–	–	100–700 μg/m^3	22

Table 6: Health Studies of Involuntary Smoking (Wadden,1983)

Health Study	Number of Subjects (age)	Results	References
Occupationally exposed smokers and nonsmokers, 83% in professional, technical, or managerial positions (southern California)—spirometry	2100 (middle aged, 40's)	Nonsmokers exposed at work had lower values on lung function tests which are related to significantly reduced small airway function, FEF_{25-75} and FEF_{75-85}.	White and Froeb (1980)
British children of smoking parents—questionnaire	2205 (<5)	Parental smoking the cause of increased respiratory disease in first year of life: ~3 additional cases of pneumonia or bronchitis per 100 children for each adult smoker.	Colley et al. (1974); Leeder et al. (1976)
Children of smoking and nonsmoking parents—spirometry; questionnaire	444 (5–9)	FEF_{25-75} lower for children of smoking parents vs. children of nonsmoking parents.	Tager et al. (1979)
Children of smoking and nonsmoking Finnish mothers	12,000 (<5)	Children of smoking mothers (matched by marital status, maternal age, and socioeconomic status) had significantly higher morbidity (mostly respiratory disease) and were more likely to be hospitalized and for longer periods of time than children of nonsmoking mothers. Most pronounced effect in morbidity in first year of life.	Rantakallio (1978a, b)
Patients with angina; 15 cigarettes in 31-m^3 room in 2 hr—cardiovascular measurements	10 (40–60)	Increased measures of cardiac function and decreased duration to anginal pain.	Aronow (1978)
Gas-electric stove studies—spirometry; questionnaire	808 (6–7) 8120 (6–10)	More respiratory disease in homes with smoking parents.	Florey et al. (1979); Speizer et al. (1980)
Nonsmoking Japanese wives	91,540 (⩾40)	Wives of heavy smokers had significantly greater risk of developing lung cancer; age-occupation standardized annual mortality rates for lung cancer 8.7/100,000 for wives of occasional or nonsmokers; 14/100,000 for wives of exsmokers or those smoking ⩽19 cigarettes/day; 18.1/100,000 for wives of those smoking ⩾20 cigarettes/day. The relative risk of passive smoking was about $\frac{1}{3}$ to $\frac{1}{2}$ that of direct smoking.	Hirayama (1981)
Nonsmoking Greek women	189 (mean age = 62–63 years)	Statistically significant difference between cancer cases (40) and other patients (149) with respect to husbands' smoking habits. Relative risks of lung cancer were 2.4 for those with husbands who smoked <20 cigarettes/day and 3.4 for >20 cigarettes/day. Tentatively, the relative risk of passive smoking was 80% of that for direct smoking, but with broad confidence limits.	Trichopoulos et al. (1981)

2.2.12 Hydrocarbons:

Different organic compounds are available for human use, such as deodorants, shaving creams, window and oven cleaners, pesticides, dust removing agents and many others. Most of these compounds are hydrocarbon chemicals. Table 7 illustrates the ingredients of some of the common household aerosol sprays. Indoor gas cooking is one of the major sources of hydrocarbons. Leaking gas pipes, inefficient gas burners, and misshandling of gas cooking equipment lead to high concentrations of gas (mostly Propane) in the indoor environment, which could result in serious fires or slow death even in case of small concentrations. (Meyer,1983)The general heath effect of hydrocarbon on human health is still ill-reported; however, table 8 shows exposure response data for some hydrocarbons used in solvents and cleaners.

Finally, Table 9 lists the maximum allowable indoor concentration for the most important pollutants.

Table 7: Ingredients in six Aerosol Spray Products (Meyer,1983)

Housekeeping Product	Ingredients
Furniture polish	Dinitrobenzene, 1,1,1-trichloroethane, petroleum distillates, silicone, wax morpholine
Spot remover	Perchloroethylene
Oven cleaner	Sodium hydroxide, hydroxyethyl cellulose, polyoxyethylene fatty ethers
Drain cleaner	1,1,1-Trichloroethane, petroleum distillates
Lysol	o-phenylphenol, *N*-alkyl-*N*-ethyl morpholinium ethyl sulfates
Clorox	4-Chloro-2-cyclopentylphenol, diethanolamide-lauric acid amide
Tile cleaner	Tetrasodiumethylenediamine
Prewash treatment	Perchloroethylene, petroleum distillates
Window cleaners	Sodium nitrite, isopropyl alcohol, ethylene glycol, ammonium hydroxide
Disinfectant sprays	Triisopropanolamine morpholine
Air fresheners	Propylene glycol morpholine, ethanol
Personal use	
Deodorant spray	Hydrated aluminum chloride, isopropyl myristate talc, triglycerides
Hairspray	Vinyl acetate copolymer resins, polyvinyl-pyrolide resins, ethanol, lanolin
Shaving foams	Stearic acid, triethanol amine, menthol, glycerine
Paint sprays	
Protective coatings	Polyurethane
Stain	Hydrocarbons, ethers
Metallic plating	Hydrocarbons, resins
High-temperature coating	Hydrocarbons, resins
Craft spray	Petroleum distillates
Glass frosting	Toluol, xylol
Primer	Toluol
Adhesive	Petroleum distillates
Glaze	Toluol, xylol
Varnish	Petroleum distillates

Table 8: Active Ingredients in Household Solvents and Its Health effects (Meyer,1983)

Compound	Use	Indoor Air Level (ppm)	Indoor Air Level (mg/m³)	Exposure-Response Data
Methylene chloride	Paint remover	200	720	180–200 ppm per day results in increment of 4.5% COHb. Narcosis above 4000 ppm. Brain damage reported above 500 ppm.
Perchloroethylene	Cleaning fluid	100	670	100 ppm for 7 hr produced narcotic effect, headache, mild eye and respiratory irritation.
Naphtha	Paint thinner	200	900	Multiple hydrocarbon content (TLV based in nonane, xylene)
Benzene, toluene, xylol, xylene	Lacquer and cement solvents	10	30	Myelotoxicant; skin absorption can produce chronic poisoning. Nausea, narcosis above 200 ppm. Neurological and vascular effects reported in workers. May contain 6–15% ethyl benzene.
Methanol	Shellac and varnish thinner	200	260	No worker injury at average 160–780 ppm. Repeated exposure above 3000 ppm may result in cumulative body concentration.

Table 9: Summary of the maximum allowable indoor concentration of the indoor air pollutants

Indoor Pollutant	Maximum Allowable Indoor Concentration
Carbon Monoxide	35 ppm
Carbon Dioxide	1.5 %
Nitrogen Dioxide	28 %
Sulfur Dioxide	20 ppb
Formaldehyde	5 ppm
Ozone.	0.3 ppm

2.3 Indoor Air Quality Models:

Mathematical modeling has been a very important tool in all fields of science for simulating the actual conditions of a problem with the lowest possible cost. IAQ is not an exception. Many models have been developed for simulating IAQ in buildings by mass balance for pollutants flow into and out of an indoor volume. Indoor air quality modeling can be used for diagnosing indoor air quality , and can assist in the design of HVAC system to provide an acceptable Indoor Air Quality. Before discussing any kind of IAQ models, it is necessary to define the common IAQ variables or the factors affecting indoor air quality, which will be used in the models later.

2.3.1 IAQ Variables:

Indoor pollutant concentrations are affected by outdoor concentrations of pollutants, the availability of indoor sources, the exchange rate of Indoor Air, indoor volume, pollutants' characteristics, and pollutant removal rate. Those factors and others are discussed below in detail, due to the need to understand such factors and how are they integrated.(Nagada,1987)

2.3.1.1 Outdoor Concentrations:

Indoor air originates from the outside environment and is usually considered "Fresh air". Unfortunately the freshness of outdoor air is relative and differs from one location to another depending on the availability of outdoor pollutant sources. High outdoor pollutant concentrations are therefore reflected in the indoor environment. Figure 2 illustrates data collected for indoor and outdoor concentrations of pollutants at the same time. It clearly indicates the link between the two without outdoor air cleaning before it gets to the indoors.

2.3.1.2 Indoor Sources:

Indoor pollutant sources may be classified in to two main categories: continuous generation sources and interrupted generation sources. Pollutant emission from building materials is an example of continuous sources.

Formaldehyde emission from building materials such as foam insulation is an example of the continuous generation of pollutants. However the level of emission drops as the material ages, which is the reason behind high concentrations of formaldehyde in new buildings. Smoking and gas cooking are considered interrupted sources, due to the discontinuity of operation of such sources. Figure 3 demonstrates the levels of pollutants generated by gas cooking as the sources operate and stop.

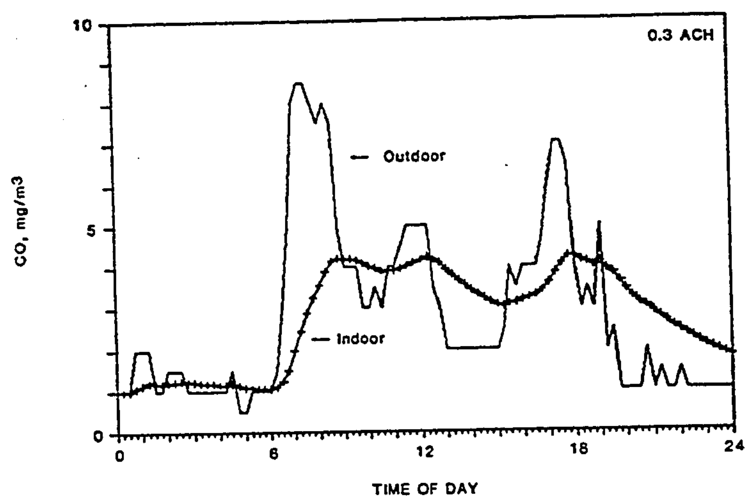


Figure 2. Effect of outdoor concentrations on indoor concentrations.(Nagada,1987)

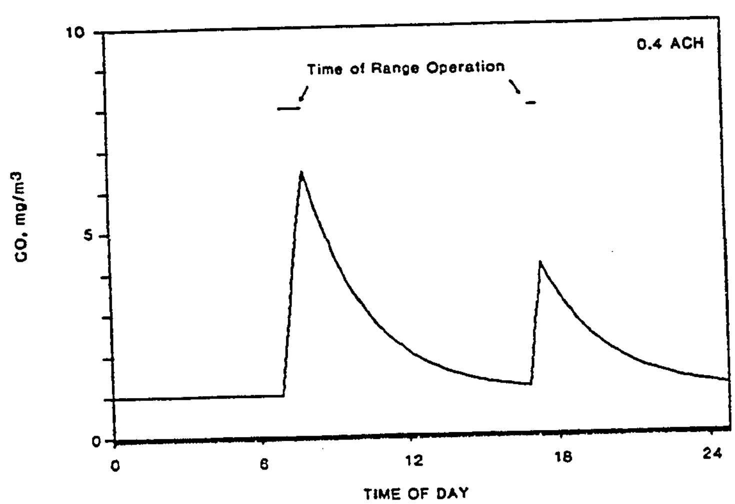


Figure 3. Effect of duration of indoor source operation on indoor concentrations. (Nagada,1987)

2.3.1.3 Air Exchange Rate:

The air exchange rate is defined as the rate at which the outdoor air substitutes for indoor air. It is expressed as the volume of air exchanged per unit of time. The air exchange rate affects the indoor pollutants positively and negatively. The positive effect is lowering the indoor air pollutant's concentration by diluting the indoor air with the relatively fresh outdoor air. The negative effect is increasing the indoor concentration of indoor pollutants, when the outdoor air is polluted. The higher the exchange rate the closer the indoor environment gets to the outdoor in terms of air constituents. As the exchange rate is lowered, indoor air characteristics differ from those of the outdoor air. Figure 4 & 5 illustrate the above graphically.

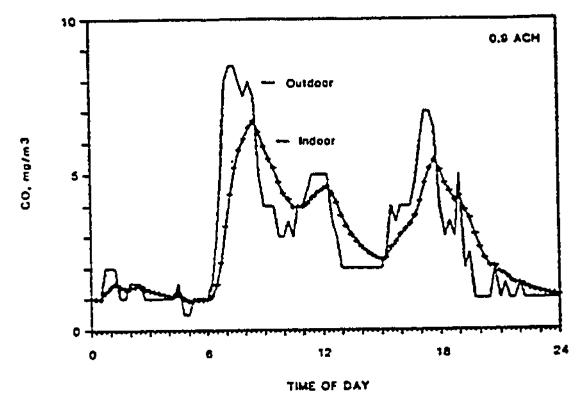


Figure 4.Effect of outdoor concentration on indoor concentration at 0.9 ACH (Nagada,1987)

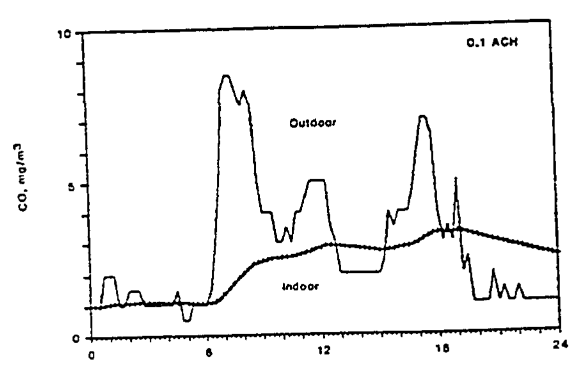


Figure 5. Effect of outdoor concentration on indoor concentrations at 0.1 ACH. (Nagada,1987)

2.3.1.4 Volume:

Indoor concentrations of pollutants are dependent on the indoor volume that pollutants disperse at. Indoor concentration is inversely proportional with the volume. The bigger the volume the smaller the concentration provided that the emission rate of pollutants is constant. Figure 6 shows the effect of volume on indoor concentration by operating a kerosene heater at two different volumes.

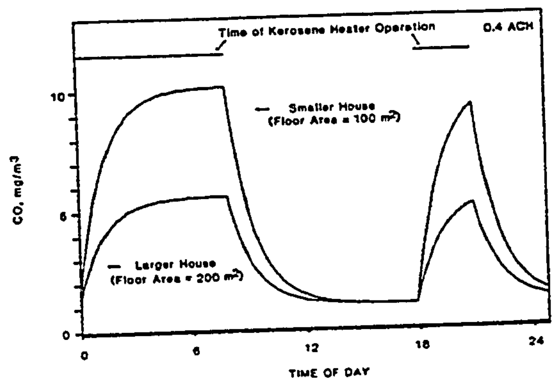


Figure 6. Effect of the volume of the structure on indoor pollutant concentration.(Nagada,1987)

2.3.1.5 Pollutant Characteristics:

Pollutant characteristics such as chemical properties and reactivity play important roles in indoor pollutant concentration. In the case of composition process Carbon Monoxide and Nitrogen dioxide are released at the same time, but behave differently as illustrated in Figure 7. The reduction of NO_2 is due its reaction with indoor building materials and other pollutants. Another example in this regard is the air exchange rate effect on HCHO." An increase in air exchange rate by a factor of two may only reduce pollutant concentration by 35% , because as the air exchange rate increases, the rate at which HCHO emanates also increases" (Nagada,1987)

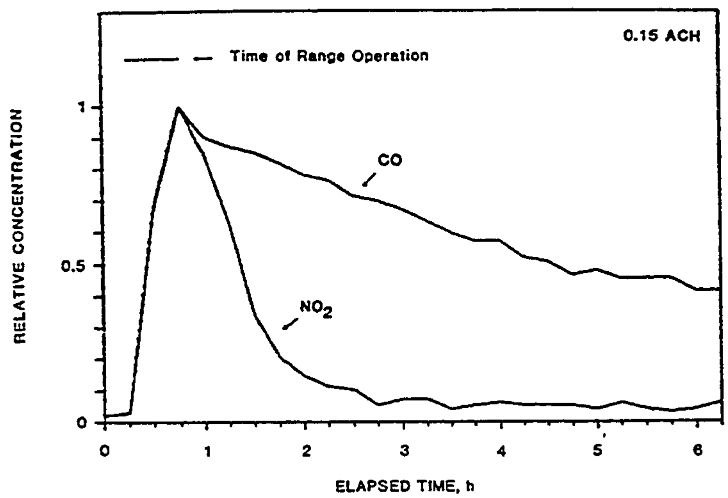


Figure 7. Comparison of decrease in NO2 and CO concentrations.(Nagada,1987)

2.3.1.6 Pollutant Removal:

Indoor used air is removed either by mechanical exhaust fans, or air cleaning devices. Exhaust fans contribute in the reduction of indoor air pollutants by removing the used indoor air with its constituents of pollutants to the outdoor environment. The location of the exhaust fan with regard to the pollutant source plays a very important role in the efficiency of removing the pollutant. A kitchen hood placed at the top of the gas cooking range will have a greater impact than an exhaust fan that ventilates the entire kitchen. Air cleaners that circulate indoor air through filtration media are used to improve indoor air quality without introducing unconditioned outdoor air for energy conservation measures.

2.3.1.7 Other Variables:

The previously mentioned variables are the most common ones that are used in almost all models. Some other factors are also used, such as filter efficiency, and air mixing efficiency. Filter efficiency differs according to the type of filters used in the HVAC system. It varies from 5% - 95% for HEPA filters. The HVAC system is responsible for mixing the introduced fresh outdoor air with the indoor air. This mixing process is not usually done properly; therefore, some IAQ models have a factor to account for the inefficiency of the air mixing. (Nagada,1987)

2.3.2 One Compartment Model:

This model is based on the mass balance for pollutant flow into and out of an indoor volume. This model is expressed by the following two equations: (Wadden, 1982)

Air mass balance : $q_0 + q_2 = q_3 + q_4$ (1)

Pollutant mass balance:

$$V\frac{dC_i}{dt} = kq_0C_0(1-F_0) + kq_1C_i(1-F_1) + kq_2C_0 - kC_i(q_0+q_1+q_2) + S - R \qquad (2)$$

Where :

Ci = Indoor concentration of a pollutant

Co= Outdoor concentration of a pollutant

q_0= Volumetric flow rate for make-up air

q_1= Volumetric flow rate for re-circulation air

q_2= Volumetric flow rate for infiltration air

q_3=Volumetric flow rate for exfiltration air

q_4= Volumetric flow rate for exhaust air

F_0 = Filter efficiency for make-up

F_1= Filter efficiency for re-circulation air

V= room Volume

S= Indoor source emission rate

R = Indoor sink removal rate

k = factor for inefficiency of mixing

Solving equation 2 for Ci with t, holding all the factors constant and with boundary values $Ci = Cs$ at $t = 0$, the final equation will be :

$$C_i = \frac{k[q_0(1-F_0)+q_2]C_0 + S - R}{k(q_0+q_1F_1+q_2)}[1-e^{-(k/V)(q0+q1F1+q2)t}] + C_se^{-(k/V)(q0+q1F1q2)t} \qquad (3)$$

for the case where R is a first-order function of Ci, the solution will have the form

$$C_i = \frac{k[q_0(1-F_0)+C_0+S}{k(q_0+q_1F_1+q_2)+E} \qquad (4)$$

where E is a proportionality constant for the particular pollutant of interest, such that $R=ECi$ and letting t approach ∞.

By applying the above formulas for any type of indoor pollutant, an estimate of the indoor concentration of any type of pollutant will be achieved. The other variables in the formula could be adjusted (i.e. increasing the make-up air, using high efficiency filters) to get the desired indoor concentration of the pollutants as permitted by health standards.

2.3.3 IAQ Comfort Model:

Most of the mathematical models developed for IAQ applications rely mostly on variables that must be measured from the space. on many occasions, readings were collected and these models were applied; the resulting pollutant concentration is according to standard. However complaints from IAQ still exist. That is mainly because the comfort issue of IAQ is not a part of these mathematical models. A new model that considers IAQ comfort was developed (Fanger,1989). The model and its units are discussed below.

2.3.3.1 New Units:

The available units of measurements quantify the volume of a certain pollutant in the indoor air such as part per million (ppm) units or weight per volume (g/m^3). However, such units do not reflect how the indoor air is perceived by the occupant. Two new units were introduced for this purpose (Fanger,1988). Olf and decipol are the new unit for quantifying the source strength of air pollutants, and for quantifying perceived air pollution.

The olf unit: this term was derived from the Latin "olfactus" which means olfactory sense. It is defined as " the emission rate of air pollutants (bioeffluents) from a standard person" (Fanger,1988)(Figure 8). This rate is measured by the percentage of the dissatisfied persons when interning a space at different ventilation rates (Figure 9). Human bioeffluents were used as the base for this unit due to the abundant knowledge on how bioeffluants are perceived by other human beings and following the classical theory that the human being is the dominant polluter in non-industrial buildings.

Figure 10 demonstrates the olfs produced by other pollutants, and Table 10 list olf values for some pollution sources.

The decipol unit: this term was derived from Latin" pollutio" which means pollution. It is defined as "the pollution caused by one standard person (one olf) ventilated by 10 l/s of unpolluted air" (Fanger,1988).(Figure 11)

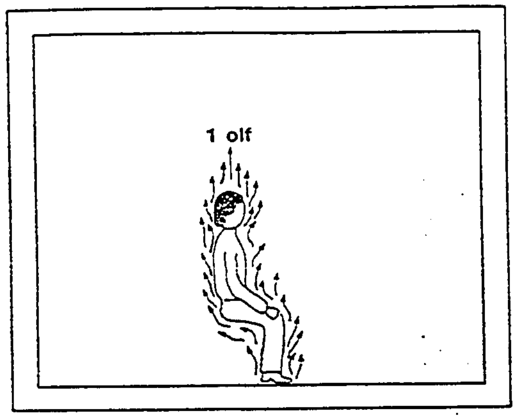


Figure 8. One olf is the air pollution from one standard person (Fanger,1988)

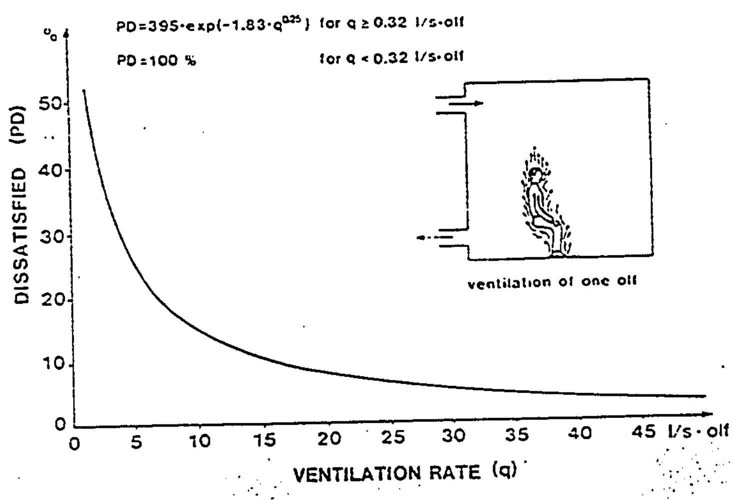


Figure 9. Dissatisfaction caused by one olf at different ventilation rates (Fanger,1988)

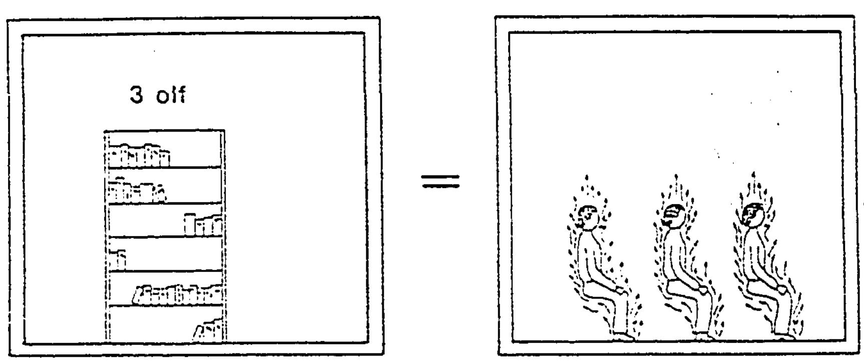


Figure 10. A pollution source has a strength of 3 olf if the pollution from three standard persons causes the same dissatisfaction as the source (Fanger,1988)

Table 10 : Olf Values for Pollution Sources (Fanger,1988)

Pollution Source	Olf Values
Sedentary person,1 met	1 olf
Active person, 4 met	5 olf
Active person, 6 met	11 olf
Smoker, when smoking	25 olf
Smoker, average	6 olf
Materials in offices	0-0.5 olf/msq floor

The decipols are measured for a certain space by panels of human subjects. The panel should judge the acceptability of the air immediately after entering the space. Before each judgment the panel should stay a few minutes in a space with low pollution. The perceived air pollution in decipol can then be found from the curve illustrated in Figure 12. The decipole readings could then be compared with available pre measured values presented on decipol scale in Figure 13.

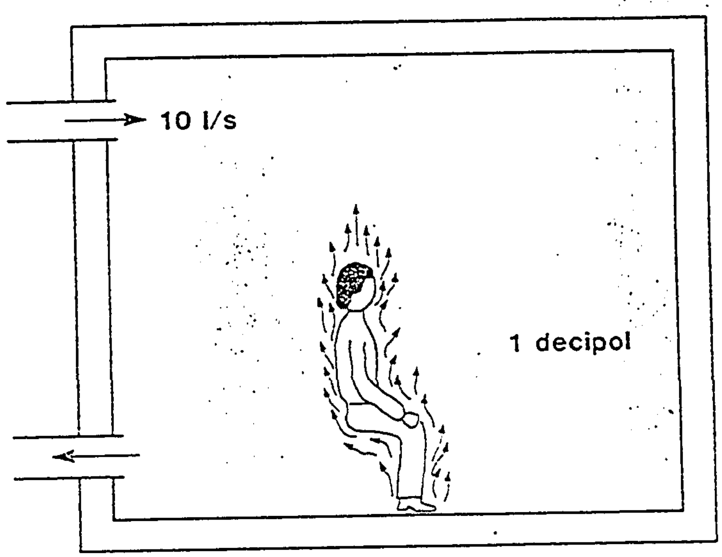


Figure 11. One decipol is the perceived air pollution in a space with a pollution source of one olf ventilated by 10 l/s of unpolluted air.(Fanger,1988)

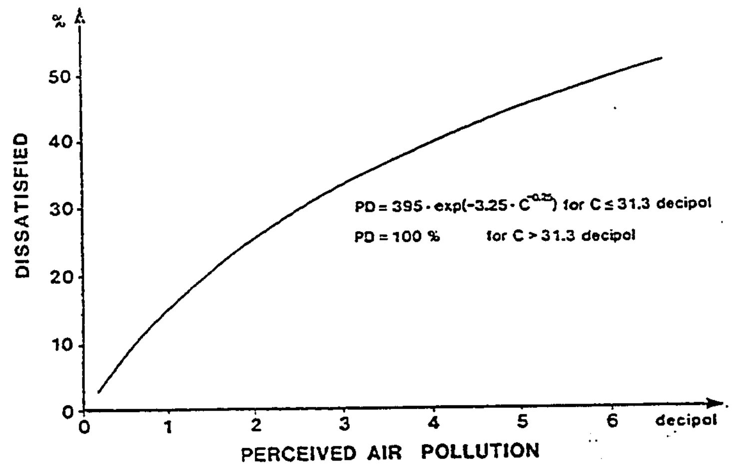


Figure 12. Percentage of dissatisfied as a function of the perceived air pollution in decipol.(Fanger,1988)

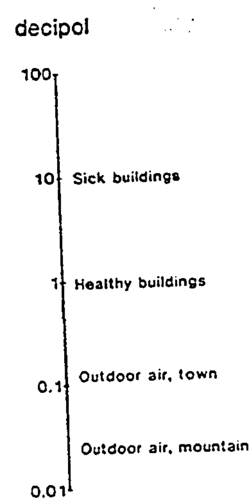


Figure 13. The decipol scale for perceived air pollution (Fanger,1988)

2.3.3.2 Comfort Equation:

After defining the new units that quantify the emission rate of indoor pollutants and the perceived air pollution, an indoor air quality comfort equation that uses these units was developed (Fanger,1989).

$$C_i = C_o + 10\frac{G}{Q} \quad (5)$$

Where Ci = perceived air quality in the space (decipol)

C0= perceived air quality outdoors

G= pollution source strength in the space and the corresponding ventilation system (olfs)

Q= outdoor air supply rate (l/s)

Rearranging equation 5 as a function of Percentage Dissatisfied (PD), it will be:

$$Ci = 112(\ln(PD) - 5.98)^{-4} \quad (6)$$

Equation 6 is the final form of the IAQ comfort equation, that could be used for design, evaluation, and diagnosis of IAQ.

2.4 Indoor Air Quality Monitoring

A building is defined as sick if 20 percent or more of that building's occupants exhibit symptoms of headaches, nausea, dizziness, sore throats, dry or itchy skin, nose irritation or excessive fatigue. The 20 percent specified here is based on the acceptable air quality definition by ASHRAE. This figure is used mostly as a rough guide line figure to quantify the issue.

Indoor air quality problem identification starts with occupants' complaints about the indoor environment in general (rooms are either too cold or too hot, they have insufficient light, odors and still air). Generally, occupants know little about sick buildings and would relate any symptoms they feel to their own health problems. Without the proper investigation by the building owner and his operation and maintenance staff, small IAQ problems might get out of control and lead to a full scale Sick Building Syndrome.

IAQ problems rang from simple problems that can be solved easily by corrective measures (i.e. adjusting fresh air damper, cleaning air filters) to complex problems that require intensive monitoring and testing procedures. Below are the major phases of IAQ investigation: (Hansen,1991)

1- Preliminary Assessment

2- Walk Through Inspection

3- Complex Diagnostics

An indoor Air Quality problem could be solved by going through the first phase, the first couple of phases, or all the phases for more serious problems. Below are these phases in details.

2.4.1 Preliminary Assessment:

The main purpose of this phase is to collect information about the IAQ complaints. The collected information would provide better understanding of the extent of the problem, and identify possible causes. Building occupants (complainants) should be interviewed about the details of the symptoms that they suffer from. Example questions in this regards would be : How long have you worked in the area?, What symptoms have you experienced ? and Do you suffer from any medical problems? .

When there are many complainants in many different locations of the facility, it might be easier and more economical to collect complaint data by means of a questionnaire, which should be self- administered and easy to use by all occupants with different education backgrounds.

Background information about the facility in hand should be part of this phase. Design, construction, commissioning, and operation and maintenance information should be collected. Comparing the design intent of the building with the existing situation, might suggest solutions to the problem. Testing and balancing data that were collected at the building commissioning stage might make the picture clearer. Operation and maintenance procedures are also very important and in many instances lead to a solution to the IAQ by adjustment or alternation of corrective or preventive maintenance procedures.

At this phase the solution - oriented approach suggested by NIOSHA (National Indoor Occupancy Safety and Health Association) could be used. This approach advises that checks should be made in areas where the problems are most likely to exist. Table 11 exhibits some studies performed by, NIOSH, Honeywell, and HBI with different areas of likelihood for IAQ problems.

Table 11. Sick buildings Problems (Hansen,1991)

Org. NIOSH	HONEYWELL	HBI
Bldgs. 529	50	223
Yr 1987	1989	1989
Inadequate ventilation (52%) Inside contamination (17%)	Operations & Maintenance – energy mgmt. – maintenance – changed loads	Poor ventilation – no fresh air – inadequate fresh air – distribution
Outside contamination (11%) Microbiological contamination (5%)	Design – ventilation/ distribution – filtration – accessibility/ drainage	Poor filtration – low filter efficiency – poor design – poor installation
Building fabric contamination (3%)	Contaminants – chemical – thermal – biological	Contaminated systems – excessively dirty duct work – condensate trays – humidifiers

2.4.2 Walk Through Inspection

If the previous phase has not resulted in finding solution(s) for the sickening indoor environment, the next phase (walk through inspection) ought to be performed, following the foot steps of the preliminary assessment phase. However, at this time the inspection involves a more thorough examination and more hands on experience and simple measurement techniques. This phase should be performed by personnel with extensive experience in HVAC system design, construction and maintenance.

The inspection team should use the data collected in the previous team and use it for comparison with collected measurements such as temperature, relative humidity, and CO_2 measurements. In this phase, the inspection team has to inspect HVAC system components looking for construction, and/or operation and maintenance flaws that affect IAQ negatively.

2.4.3 Complex Diagnostics Phase

If all previous methods' recommendations did not resolve the IAQ problem, a more complex, time consuming, and expensive phase should be started. The main purpose of this phase is to look for the indoor pollutants that resulted in IAQ problems directly by means of measuring, and testing procedures instead of looking for flaws in the building systems that could have resulted in IAQ problems.

In this phase, the location of the high complainant population should be scheduled for monitoring. Also other selected areas with no complaints should also be measured to use them as a reference point.

2.4.3.1 Monitoring Instruments :

Instruments for monitoring different kinds of indoor air pollutants will be needed throughout this phase. The monitoring instruments referred to here are the commercially available preassembled devices. Before starting monitoring tasks, selection of these instruments should take place with the following criteria:

1- Sampling mobility,

2- Operating characteristics, and

3- Output characteristics

Sampling mobility refers to the method of collecting samples regarding ease of moving and relocating the instrument. Monitoring instruments can be classified to three mobility classes:

1-Personal: small in size, and could be carried or worn

2- Portable: Bigger than portable instruments, but could be hand carried from one place to another

3- Stationary: must be operated from fixed location

The monitoring task dictates the needed mobility. If the task is simple, the required monitoring is instantaneous, and a maximum of two pollutants would be measured, it would be appropriate to use personal instruments. In case of the need for monitoring over a period of time and more than two types of pollutants are needed to be monitored, the portable type is the class to consider. Stationary instruments are mostly used in specialized labs for testing collected samples.

Two categories of operating characteristics exist for monitoring instruments: active and passive. In the active ones, the air sample is drawn by the instrument to the inside of the instrument for analyzing or collection. The other category, passive, relies on diffusion for air to enter the instrument.

The output characteristics fall into two categories: First, the analyzer, analyzes the sample of air as soon as it gets in to the analysis mechanism of the instrument. No further analyses could be made and the analysis could be done over a period of time. The other category is the collector, which only collect samples for testing later by analysis instruments.

CHAPTER 3: RESEARCH METHODOLOGY

The purpose of this chapter is to present the research methodology that will be followed in order to achieve the objectives of this research.

3.1 Achieving the First Objective:

The first objective is to identify the problems associated with IAQ. This objective is achieved from the IAQ literature. According to the literature there are two classes of IAQ problems: 1) Building related IAQ problems and 2) Occupants related IAQ problems. The first are the IAQ problems resulting from building design and operation and the maintenance trends of the buildings. The second class are the symptoms occupants experience during occupation.

3.2 Achieving the Second and Third Objectives:

The assessment of the contribution of the building design and operation and maintenance on IAQ will be achieved by collecting building data related to IAQ as indicated in Section 3.1 above. The collected data will include operation and maintenance practice, HVAC system information and the architectural system information. Such data will be gathered by three methods:

1- Self- administered questionnaires to be filledout by building owners or managers. Appendix B presents this questionnaire in full detail.

2- Building manager interviews and building tours. The main purpose of this step is to follow up on the questionnaire and compare data from the questionnaire with interview and tour remarks.

3- Review building *As Built* drawings, operation and maintenance manuals and available maintenance records.

3.3 Achieving the Fourth objective:

In order to assess the occupants' response to IAQ the self-administered questionnaire presented in Appendix B will be distributed among building occupants to collect occupants opinions about the indoor environment in general and IAQ in particular. This questionnaire is based on the identified IAQ mentioned in Section 3.1.

The occupants' questionnaire is composed of five major parts. The first part is about the respondent's background: age, occupation, nationality and space occupancy questions. The second part is seeks the occupants' evaluation of the indoor environment. The third part is about symptoms that occupants might have experienced during their work in the office, which are important in evaluating the surveyed buildings. The fourth part is about the occupants' overall evaluation of the indoor environment in his office. The last part is a space left blank for the occupants additional comments.

3.4 Achieving the Fifth Objective:

The assessment of the possible existence of IAQ in Saudi buildings will be achieved by the analysis of the outcome of the building and occupants surveys based on ASHRAE definition of IAQ for the occupant's survey and the IAQ evaluation criteria for building systems.

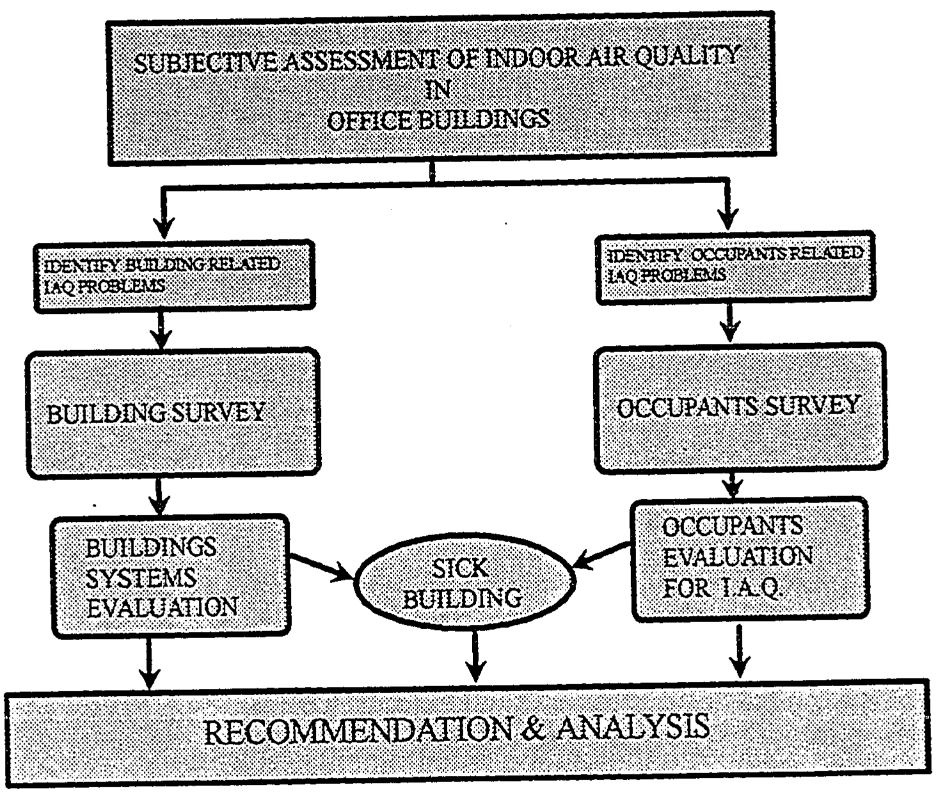


Figure 14: Research Methodology

3.5 Population and Sample:

Office buildings in Dammam and Khobar that satisfy the scope and limitations of this research are listed in Appendix A. These buildings have been selected by the aide of Al-Farisi maps for the Eastern Province and by touring the cities. The list contains 56 buildings that could be considered as the total population of the office buildings that satisfy the criteria of this research. The minimum number of buildings that represent the total population (sample) can be calculated based on the following formula (kish,1965) :

$$n = \frac{n'}{(1+\frac{n'}{N})} \qquad n' = \frac{S^2}{V^2}$$

N = Size of the finite population

S^2 = The variance of population elements. It is estimated by S^2 = P(1-P) and the max. value is chosen at P= 0.5

V = Standard deviation of the sampling distribution . 0.05 is a reasonable estimate of V

P = Proportion of the population elements that belong to the defined category.

By applying the above formula on the office building population of 56 buildings. The sample size will be :

$$n' = \frac{0.5^2}{0.05^2} = 100$$
$$n = \frac{100}{1+\frac{100}{56}} = 36 \text{ buildings}$$

Assuming 65 % response rate for this study, the survey questionnaires will be sent to all 56 buildings.

CHAPTER 4: RESULTS AND DISCUSSION

The purpose of this chapter is to explain what has been achieved in this research. The layout of this chapter will follow the sequence of the research objectives. Each objective will be discussed in terms of the following: 1) What has been done to achieve that objective, and 2) the fulfillment of that objective.

4.1 Problems Associated with IAQ

Identifying the problems that are associated with IAQ is the first objective. These problems have been identified in the literature review; therefore, this objective is achieved by summarizing theses problems in the format that serves the objectives of this research. Problems associated with IAQ can be classified into two categories:

1) Occupant related problems

2) Building related problems

4.1.1 Occupants Related Problems

Occupant problems resulting from low IAQ have been identified in the literature as a group of symptoms experienced by the occupants during their work in the building. Table 12 below lists the most common symptoms of this nature, which will be used in this research. These symptoms could cause a reduction in occupants' productivity and/or develop into more serious illnesses and will be called building related illness (BRI).

Table 12. IAQ related common symptoms

Headache	Shortness of breath	Dry Skin
Heavy head	Chest pains	
Eye Irritation	Nausea	
Nose Irritation	Fatigue	
Throat Irritation	Drowsiness	
Dry mouth	Difficulty in Concentration	

4.1.2 Building Related Problems

Building IAQ related problems can be classified in to three main categories:

1) Operation and maintenance

2) HVAC system

3) Architectural design

Table 12 lists the common IAQ problems related to each category. The main purpose of this list is to briefly list these problems which partially achieve objective number one of this research and will be used for achieving other objectives.

4.2 Research Surveys

According to the research methodology, the required information for achieving the remaining objectives of this research are collected by means of surveys. According to the research methodology layout in chapter three, two kinds of surveys are to be performed : 1) occupant survey 2) buildings survey. Each of those surveys is discussed in detail below.

4.2.1 Occupant's survey

The purpose of this survey is to gather an occupant's IAQ related information, which is the occupant's assessment of various aspects of IAQ and the symptoms that he might have experienced during space occupancy due to low IAQ. However, these symptoms could have been caused by other factors around him; therefore, the occupant's questionnaire has six parts: 1) IAQ questions 2) Symptoms questions 3) Background questions 4) Thermal environment questions 5) Physical environment questions 6) Other questions. Figure 15 illustrates these parts and the questions included under them.

Category	Sub category	Problem Description
Operation and Maintenance	Building Age	1- High emission rate of formaldehyde is associated with new buildings 2- High growth of bacteria and fungi is associated with older buildings.
	Preventive maintenance	Preventive maintenance for building systems would result in efficient system operation and ensure system cleanness.
	Housekeeping	1) Low rate of general building cleaning would result in low hygiene for the building , which effect IAQ negatively. 2) Excessive use of detergent would increase the concentration of VOC's in the indoor air 3) Excessive carpet cleaning would leave carpet moist which make it a suitable environment for bacteria and other microorganisms.
HVAC system	System Selection	Chilled water fan coil unit system or Dx unit tends to be moist and have drain pan. These units if not cleaned properly, they would be a good environment for bacteria and micro-organisms.
	Ducting material	1) Fiberglass boards ducting release fine particles in the air stream. 2) Galvanized steel ducting has rough surfaces and dust particles tends to stick to it. 3) Stain steel ducting has smooth surface. It is the best material.
	Ducts cleaning	Internal duct cleaning by the use of high-pressure vacuum and cleaning agents would ensure cleaner ducts surfaces.
	Air filters	1)The higher the higher the efficiency of the filters, the higher the rate of air cleaning. 2)The use of more than one type of filters in the system provide the required redundancy Incas filter clogged.
	Ventilation	1) The higher the rate of exhausting indoor air and supplying fresh air the higher the quality of indoor air. 2) The use of economizer cycle (adjust fresh air supply according to outdoor temperature) provide a balance between IAQ and energy.
	System's balancing & calibration	HVAC system's components loss their initial setting with use.
	Operation mode	1) Starting the ventilation system earlier than occupancy would improve IAQ by accumulated indoor pollutants overnight.
	Refrigeration equipment location	Locating refrigeration equipment indoor would lead to spread of leaked refrigerants gases into the indoor which leads to increasing indoor air pollutants levels.
	Return air plenum	1)Using fall ceiling space as a return air duct would have a negative impact on IAQ, du to the large and rough surfaces of the plenum, which attracts dust particles. 2) Return air plenums are not tight, this lead to short circuiting the supply air.
	Humidifiers	Humidifiers become a source of indoor pollutants(bacteria and micro organisms) .
Architectural Design	Building envelop	Building envelopes with height infiltration rates allow outdoor air to enter the building without cooling or filtering.
	Interior layout	Flexible low partitioning system would increase the spread of indoor pollutants and it wouldn't be possible to control pollutants by pressure deferential.
	Parking garage	Designing parking garages within the building envelop would increase the possibility of spreading car exhaust into the building.
	Furniture	Office furniture made of particle wood and synthetic resins tends to release VOC's.

Table 13 : Building Systems IAQ Related Problems

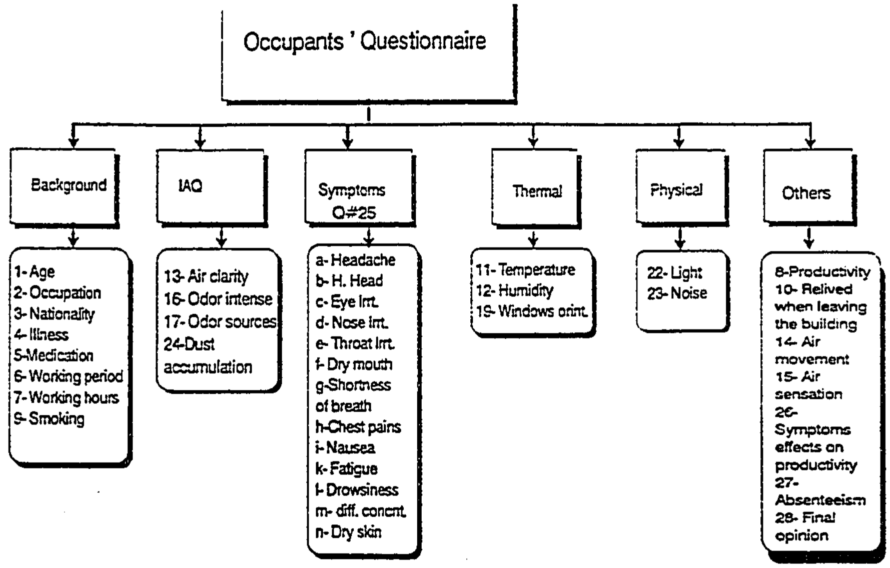


Figure 15: Occupants' Questionnaire Categories

4.2.2 Building's Survey

The purpose of this questionnaire is to gather the building's IAQ related information which is relevant for achieving objectives #2 and #3. This survey was conducted by means of a questionnaire and interviews. The questionnaire was designed based on the IAQ problems presented in Table 13. This questionnaire follows the same classifications indicated in the table. The building manager, owner or any knowledgeable O&M staff could fill in this questionnaire. The interview of the building manager is for making sure that the respondent understand the questions and if not to try to assist them in completing as much as possible of the required information.

4.2.3 Distribution and collection of Questionnaires

4.2.3.1 Pilot study:

Prior to distributing the occupant questionnaires and the building questionnaires to all the buildings, a pilot study was made for a sample of two buildings. This is important in order to investigate the respondents' reactions towards the layout and the language of the questionnaires. After performing the pilot study, some modifications were made on both questionnaires. The final version of these questionnaires is presented in Appendix B. Also some new information was added to these questionnaires based on new literature material which was not available during the preparation of the first version of the questionnaire.

4.2.3.2 Full scale study:

According to the research methodology in chapter 3 , the questionnaires should be distributed to 58 buildings, which represent the population of the office buildings that fulfill the selection criteria, in order to receive a response from 36 buildings assuming a 65% response rate. The distribution and collection of research questionnaires have gone through many stages. Below are the details of each stage.

4.2.3.3 Stage One:

The distribution of questionnaires began by visiting each building looking for either of the following : 1) building owner; 2) building manager. When either of them was found , the researcher explained that this particular building was chosen as a candidate for anIAQ survey and their permission and cooperation was needed. They were asked to fill in the building's questionnaire and help in distributing the occupants' questionnaire to as many as possible of the occupants. After completing this stage the covered buildings were found to be in any one of the following situations:

1- Agreed to contribute to the study

2- Refused to contribute to the study

3- Building did not fulfill selection criteria

Table 14 reports the outcome of this stage in details.

4.2.3.4 Stage two

For buildings whose owner or managers agreed to contribute in the study, a copy of the building questionnaire was handed to the building manager or owner for filling in. In case the building manager did not have the necessary technical knowledge , an appointment was set with his technical personnell to meet them and seek the answers for the building questionnaire.

Table 14: Stage 1 Summary

Agreed		
Ser.#	*Bld#*	*Building Name*
1	1	Rural and Municipale Affaries Building
2	2	Civil Service Beru Building
3	3	Jafaly Office Building
4	4	Hoshan Office Building
5	5	Jomih Office Building
6	7	Post Office H. Q.
7	10	GOSI Building #1
8	11	GOSI Building #2
9	12	Mujel Office Building
10	13	Dammam Muncibilty New Office Building
11	14	KAMO Office Building
12	15	Mujel H.Q.
13	16	Gazawi Office Building
14	17	Mulihe Office Building
15	18	Fadil Office Building
16	19	Aqariah Office Building
17	22	Tamimi Office Building
18	23	Sabic Office Building
19	24	SAMAREC Office Building
20	25	Zamil Steel Office Building
21	26	Champer of Commerce H.Q.
22	27	SECECO H.Q.
23	28	Carrier Office Building
24	30	Dealm Office Building
25	34	Flour Office Building
26	35	Olian Office Building
27	36	Silver Tower Office Building
28	37	Zamil O&M Office Building
29	40	Pan Am Office Building
30	41	SUCO Office Building
31	42	SSOC office Building
32	46	SAKHAR office Building
33	43	SACAT Office Building
34	50	Khashjee Office Building
35	53	Gulf Center
36	56	KFUPM Administration Building
37	57	PI consulting office
38	58	Al-Mutlaq office building

Buildings that Don't match cretiera			
Ser.#	*Bld#*	*Building Name*	*Justification*
1	9	Chamber of Commerce Old Building	Mostly vacant
2	29	National Guard H.Q.	Window type AC
3	31	Nagi Office Building (BMW)	Not office bldg.
4	32	Aba-Hussin Office Building	Vacant
5	44	Khodary Office Building	Resedential Window type AC
6	45	Cathy Pacific Office Building	Resedential
7	47	Red Brick Building	Vacant
8	48	Kingston Office Building	Resedential
9	49	Majal Office Building	Not office bldg.
10	51	Ben-Zager Office Building	resdential
11	52	Khobar Mancupality	window type AC
12	54	Hashem building	Resedential
13	56	Jadawel Building	Resedntial

Refused		
Ser.#	*Bld#*	*Building Name*
1	6	Turky Office Building
2	8	Saudi Telephone H.Q.
3	20	Kanoo Office Building
4	21	SAMA Office Building
5	33	SNAS Office Building
6	38	Airlines Office Building
7	39	Oaisi office building

For the occupant questionnaires the building manager's help was asked for the best way for distributing the questionnaires. One or more of the following situations were found:

1-The building was occupied by one company; the occupant questionnaires were distributed by the building manager or the public relation officer.

2- The building was occupied by different tenets, the occupant questionnaire was distributed by the researcher.

In both of these situations, after distributing the questionnaires, the respondents were given one to two weeks for filling the questionnaires. Table 15 lists the buildings and the number of occupant questionnaires distributed to each building after eliminating the buildings that did not meet criteria and refused to contribute to the study according to stage one results.

4.2.3.5 Stage three

The collection of both questionnaires started in this stage. Building visits were arranged for collecting the filled in building questionnaires and occupant questionnaires. In collecting the building questionnaire the following problems were faced:

1- In some buildings a technical staff capable of filling in the questioner was not available;

2- Some building managers did not like to fill in the questionnaire themself, and preferred to answer the questionnaire questions verbally.

For the first case, a meeting was set with the available operation and maintenance personnel on site to ask them what they could answer in the building questionnaire. At times when there was no O&M personal at site and the O&M was performed by a contractor, the contractor's address was taken and he was contacted with the permission of the owner to provide the necessary information.

Table 15: Stage 2 Summary

Ser.#	*Bld#*	*Building Name*	*Dist. occupants' questionnaires*
1	1	Rural and Municipale Affaries Building	50
2	2	Civil Service Beru Building	20
3	3	Jafaly Office Building	40
4	4	Hoshan Office Building	40
5	5	Jomih Office Building	60
6	7	Post Office H. Q.	50
8	11	GOSI Building #2	50
9	12	Mujel Office Building	50
10	13	Dammam Muncibilty New Office Building	50
11	14	KAMO Office Building	20
13	16	Gazawi Office Building	30
14	17	Mulihe Office Building	50
15	18	Fadil Office Building	50
16	19	Aqariah Office Building	50
17	22	Tamimi Office Building	30
18	23	Sabic Office Building	25
19	24	SAMAREC Office Building	60
20	25	Zamil Steel Office Building	30
21	26	Champer of Commerce H.Q.	50
22	27	SECECO H.Q.	60
23	28	Carrier Office Building	20
24	30	Dealm Office Building	20
25	34	Flour Office Building	50
26	35	Olian Office Building	45
27	36	Silver Tower Office Building	60
28	37	Zamil O&M Office Building	25
29	40	Pan Am Office Building	20
30	41	SUCO Office Building	15
31	42	SSOC office Building	30
32	46	SAKHAR office Building	35
33	43	SACAT Office Building	36
34	50	Khashjee Office Building	70
35	53	Gulf Center	60
36	56	KFUPM Administration Building	50
37	57	PI consulting office	20
38	58	Al-Mutlaq office building	45

For the second case, the needed information in the building questionnaire was provided by means of interviews with the building manager and the questionnaire was filled in during the interview.

During the collection of the building questionnaire, some clarification was needed for some questions. As built drawings were reviewed for answering some questions. Also a tour in the building was arranged to see the building systems in working condition.

In collecting the occupant questionnaires during this stage, the available filled in occupant questionnaires were collected. Table 16 lists the number of collected occupant questionnaires at this stage.

4.2.3.6Stage Four

This was the last step in collecting both questionnaires. Follow up visits were arranged for building with low response. A maximum of four visits was allowed for each building for occupant questionnaire follow up. Buildings with low response after the fourth visit were eliminated. Thirty buildings will be left after this stage, which is close to the target sample (36). Also if the sample size formula is reapplied after deleting the buildings that did not match criteria and refused to contribute in the study (38 buildings are considered as the building population), the sample size will become 28 buildings.

Table 17 lists the buildings with their final number of collected occupant questionnaires.

Table 16: Stage 3 Summary

Ser.#	*Bld#*	*Building Name*	*Dist. occupants' questionnaires*	*Collected quest.*
1	1	Rural and Municipale Affaries Building	50	12
2	2	Civil Service Beru Building	20	10
3	3	Jafaly Office Building	40	3
4	4	Hoshan Office Building	40	2
5	5	Jomih Office Building	60	20
6	7	Post Office H. Q.	50	25
7	10	GOSI Building #1	50	42
8	11	GOSI Building #2	50	22
9	12	Mujel Office Building	50	6
10	13	Dammam Muncibilty New Office Building	50	10
11	14	KAMO Office Building	20	7
12	15	Mujel H.Q.	30	10
13	16	Gazawi Office Building	30	4
14	17	Mulihe Office Building	50	15
15	18	Fadil Office Building	50	18
16	19	Aqariah Office Building	50	25
17	22	Tamimi Office Building	30	10
18	23	Sabic Office Building	25	8
19	24	SAMAREC Office Building	60	19
20	25	Zamil Steel Office Building	30	2
21	26	Champer of Commerce H.Q.	50	28
22	27	SECECO H.Q.	60	30
23	28	Carrier Office Building	20	9
24	30	Dealm Office Building	20	12
25	34	Flour Office Building	50	16
26	35	Olian Office Building	45	17
27	36	Silver Tower Office Building	60	4
28	37	Zamil O&M Office Building	25	18
29	40	Pan Am Office Building	20	10
30	41	SUCO Office Building	15	0
31	42	SSOC office Building	30	17
32	46	SAKHAR office Building	35	12
33	43	SACAT Office Building	36	0
34	50	Khashjee Office Building	70	45
35	53	Gulf Center	60	15
36	56	KFUPM Administration Building	50	0
37	57	PI consulting office	20	10
38	58	Al-Mutlaq office building	45	22
		Total	1546	535

Table 17: Stage 4 Summary

Ser.#	*Bld#*	*Building Name*	*Dist. occupants' questionnaires*	*Collected quest.*
1	1	Rural and Municipale Affaries Building	50	22
2	2	Civil Service Beru Building	20	14
3	5	Jomih Office Building	60	34
4	7	Post Office H. Q.	50	47
5	10	GOSI Building #1	45	42
6	11	GOSI Building #2	50	42
7	12	Mujel Office Building	50	38
8	13	Dammam Muncibilty New Office Building	50	30
9	14	KAMO Office Building	20	17
10	15	Mujel H.Q.	30	14
11	17	Mulihe Office Building	50	32
12	18	Fadil Office Building	50	23
13	19	Aqariah Office Building	50	43
14	22	Tamimi Office Building	30	15
15	23	Sabic Office Building	25	13
16	24	SAMAREC Office Building	60	21
17	26	Champer of Commerce H.Q.	50	34
18	27	SECECO H.Q.	60	32
19	28	Carrier Office Building	20	20
20	30	Dealm Office Building	20	13
21	34	Flour Office Building	50	34
22	35	Olian Office Building	35	17
23	37	Zamil O&M Office Building	25	19
24	40	Pan Am Office Building	30	24
25	42	SSOC office Building	30	20
26	46	SAKHAR office Building	35	21
27	50	Khashjee Office Building	70	68
28	53	Gulf Center	60	46
29	57	PI consulting office	20	13
30	58	Al-Mutlaq office building	45	38
		Total	1240	846

4.2.4 Collected Questionnaire Summaries

4.2.4.1 Occupants' Survey Summary

A sample of 846 occupants in 30 buildings is the outcome of the occupants' questionnaire distribution as indicated in Table 17. The response of this sample of occupants to each of the occupants' questionnaire questions are represented in tables and bar chart formats in the forthcoming sections. The X axis of a typical graph represents the choices provided for answering a particular question plus any additional choices which were added to represent the respondent's answer as will as possible. The Y axis of the graph represents the percentage of respondents out of the whole sample (846) who chose each choice. As is the case with all questionnaires, some questions were not answered by the occupants and left blank and it is important to report the unanswered questions to check the response rate. Therefore, the percentage of respondents that did not answer the question is indicated under the heading ***missing*** in the X axis. The reported results of the occupants' questionnaire will be discussed below following the question categorization laid out in Figure 15.

4.2.4.3 Discussion:

Background Category: The first category of the occupants' questionnaire questions is the background category. Under this category lay the following questions about: 1) Age 2) Occupation 3) Nationality 4) Long term illness 5) Long term medication 6) Working period in the building 7) Daily working hours in the space 8) Smoking status.

Starting with the age question (see Figure 16), it is noticed that a high percentage (90.2%) of the respondents' ages lay between 20-50 years old. A very small percentage (6.7%) is above 50 years old. Also the unreported ages (missing) is only 3.1% . From this distribution of respondents ages, it is noticed that the distribution of respondents ages represent the actual population of working individuals, with high a percentage of younger age and lower percentage as the age gets higher.

Second is the occupation question (see Figure 17). By analyzing this chart, it is noticed that the distribution of occupants' occupation follows the normal distribution of occupations in any business. A higher percentage of people in the low and middle ranks and lower percentages as you move to the management and executives levels. Only 4.9% of the respondents did not answer this question.

Percent of occupants	Age Range (Years)
32%	20 - 30
40.2%	30 - 40
18.1%	40 -50
5.6%	50 - 60
0.9%	over 60
3.2%	Missing

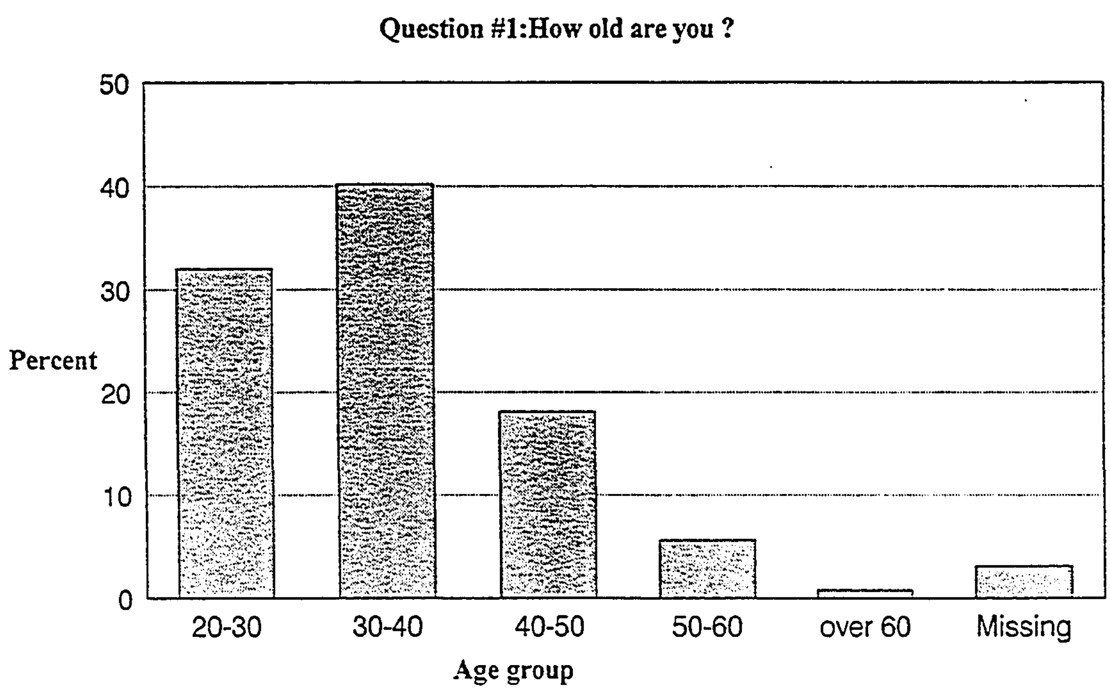


Figure 16 : Occupant's Ages

Percent of Occupants	Occupation
28.4%	Low rank employee
44.6	Middle rank employee
20.6	Manager
1.6	Executive
4.9	Missing

Question #2: What is your Occupation ?

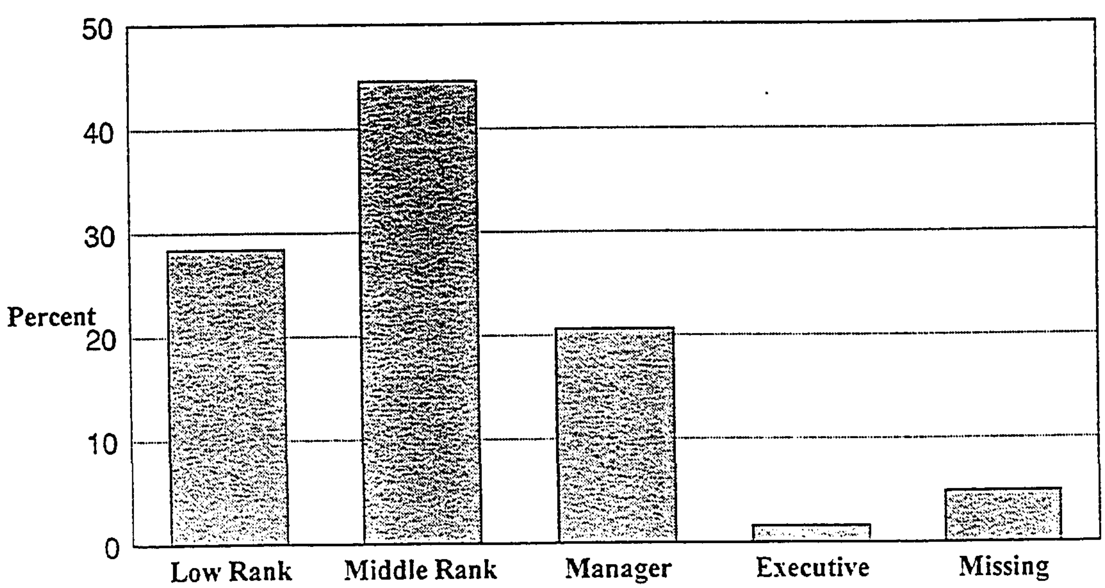


Figure 17 : Respondent's Occupations

Thirdly, concerning the nationality question (see Figure 18), from this chart, it is noticed that the occupants survey covered the available nationalities with different percentages suiting each nationality and without concentrating on a certain nationality. The Saudis, Asians and Arabs are the highest, which represents the actual distribution of them in the country. And likewise are the American and the Europeans. The missing answers for this question are only 2.8%.

Four, the long term illness (see Figure 19). This question was added in the questionnaire in order to see the effect of this factor in the reported symptoms of the occupants. 95.3% of the respondents reported they have "No" long-term illnesses and only 4.4 % of the respondents answered "Yes" they have long term illnesses. Only 0.2% of the respondents did not answer this question. Due to the low percentage of respondents with long term illness, the effect of this factor is considered irrelevant. However, this factor will be analyzed to see its relation to symptoms in this small percentage. The same is true for the long term medication question (see Figure 20).

The time period (in years or months) the respondent spent in the building and the hours he spends daily in the office are very important, because it determines the exposure period of the occupant to the indoor pollutants. From the charts (see figures 21 and 22) it is noticed that 96.6% of the respondents worked in their buildings more than two months and only 3.1% worked one month or less. Due to the low percentage of the last group, the whole sample of the respondents will be considered. The same is true for question # 7.

The last question to consider in the background category is the smoking status of the respondents. The smoking statues of the respondent is important in evaluating his response to the IAQ due to the following:

1- Smoking is a prime source of indoor air pollutants
2- Smokers tend to experience some symptoms due to smoking

The chart of the respondents' smoking status (see Figure 23) indicates that 70.3% of the respondents are not smokers and 29.3% are smokers. Therefore it is concluded that the smoking effect should be considered in the analysis of the occupants' questionnaire due to the relatively high percentage of smokers.

Percent of Occupants	Nationality
35.3%	Saudi
22.4%	Arab
28.3%	Asian
3.2%	European
8%	American
2.8%	Missing

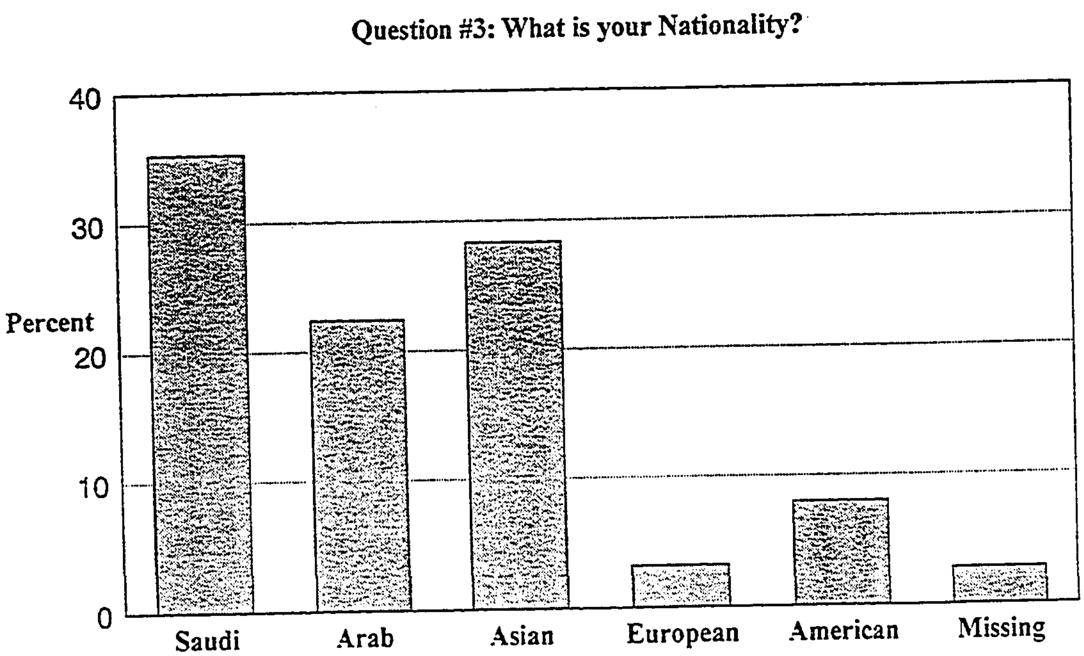


Figure 18 : Occupant's Nationality

Percent Of Occupants	Long term Illness
4.4%	Yes
95.3%	No
0.2%	Missing

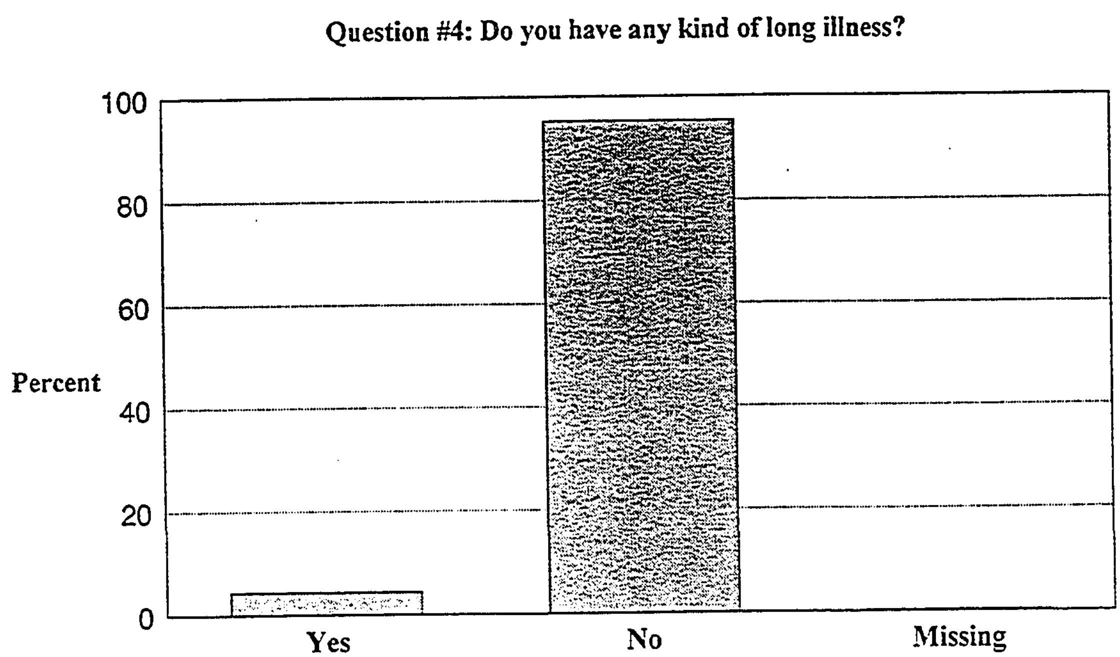


Figure 19 : Long term illness

Percent of occupants	Long term medication
4.8%	Yes
94.9%	No
0.4%	Missing

Question #5: Do you take any long term medication?

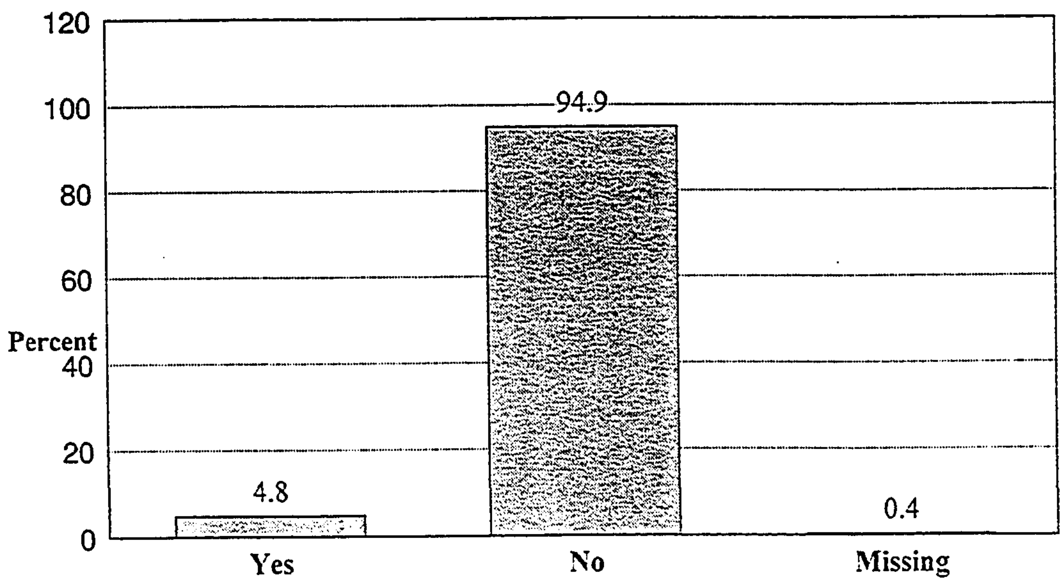


Figure 20 : Long term medication

Percent of occupants	Working Period
3.1%	One month or less
12%	2 - 6 months
10.4%	6 - 12 months
74.2%	More than one year
0.2%	Missing

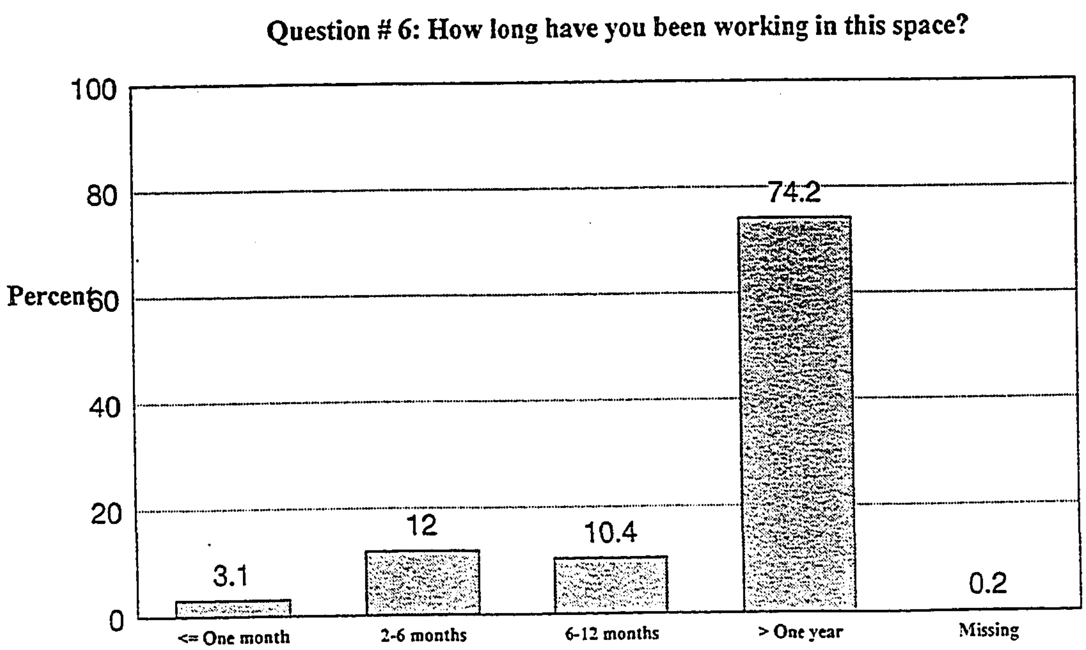


Figure 21 : Working period in the space

Percent of occupants	Working Hours
1.6%	One hour or less
5.6%	2 - 4 hours
2.3%	4 - 6 hours
90.1%	6 - 8 hours
0.2%	8 - 12 hours
0.2%	Missing

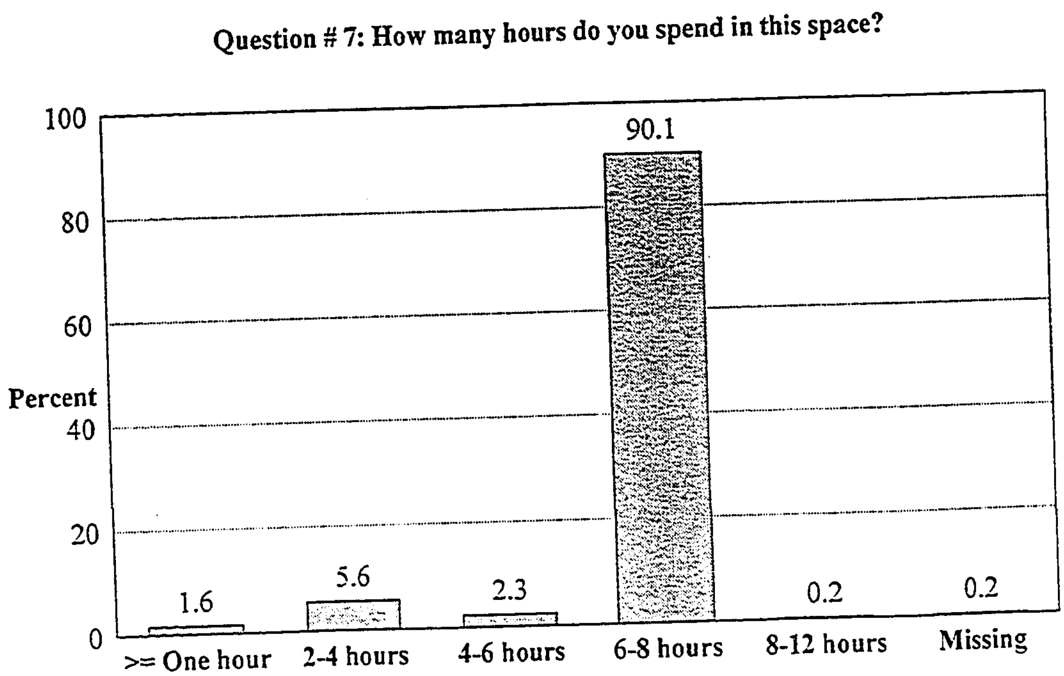


Figure 22 : Working hours

Percent of occupants	Smoking
29.3%	Yes
70.3	No
0.4%	Missing

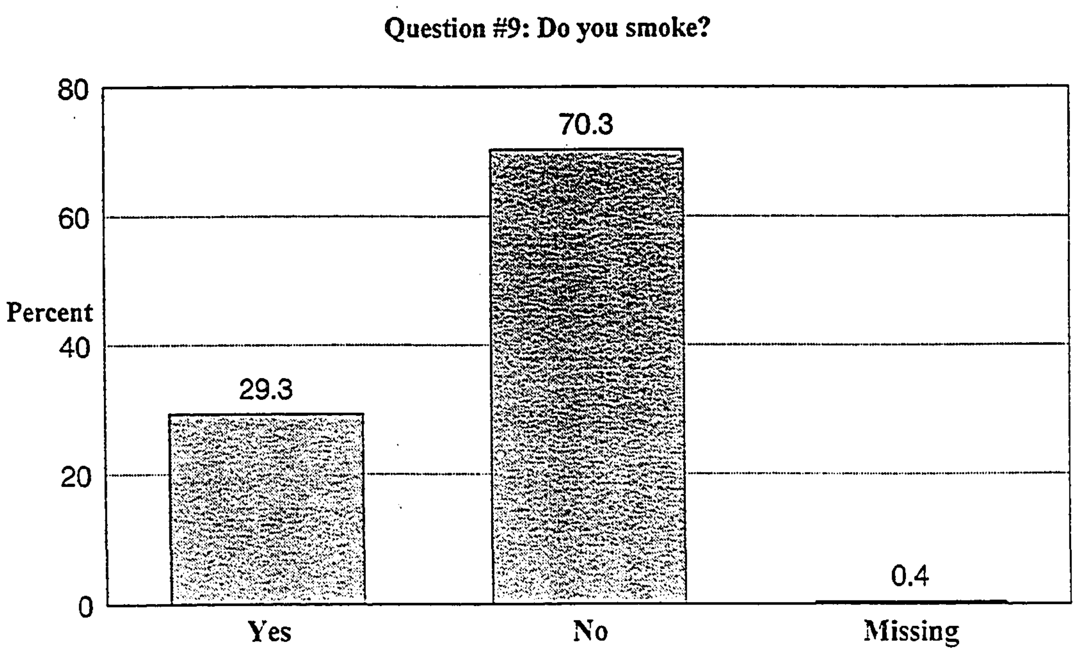


Figure 23 : Smoking Status

Thermal category : Three questions are considered under this category . Those questions are about room temperature, humidity, and window orientation . The purpose of these questions is to seek the response of the occupant about the thermal environment provided for him . This is going to be analyzed against the reported symptoms as to how strong it's effect and compare it with other categories.

Question # 11 in the occupants questionnaire's tackles the room temperature. As indicated in the chart (see Figure 24) 46% of the occupants reported neutral room temperature. The cumulative percentage of respondents reporting cold, cool, and slightly cool is 35.5% . On the other hand , 12.26% reported slightly warm, and hot. This indicates that the temperature is usually on the cool side than on the hot side. About 5% of the respondents reported fluctuating room temperature from cool to hot . The fluctuation of room temperature plus the higher percentage of complaints in the cold side of the scale indicates the existence of HVAC system control problems.

The second factor to consider on this category is the air humidity. From the chart (see Figure 25) 70.2% of the respondents reported normal and 19.7% reported very dry and dry. Only 9.7% reported humid and very humid. This result coincides with the result in the temperature chart. This happens because the air releases its moisture contents at low temperatures (dehumidification process).

The last factor in this category is window orientation. However, before asking about the window orientation window availability had to be checked first. Therefore question # 18 about window availability was asked and the result is presented in Figure 26.

The chart indicates that 73.5% of the respondents have windows in their offices and 25% do not have windows.

Regarding the window orientation question, as can be seen from the chart (see Figure 27) 26.7% of the respondents did not answer this question. Comparing this percentage with the 25% of the respondents who have no windows as mentioned earlier, explains this high percentage because respondents who do not have windows will skip the window orientation question.

Percent of occupants	Room temperature
4%	Cold
15.3%	Cool
16.2%	Slightly cool
46%	Neutral
7.8%	Slightly warm
4.4%	Warm
0.6%	Hot
4.9%	Fluctuating
0.8%	Missing

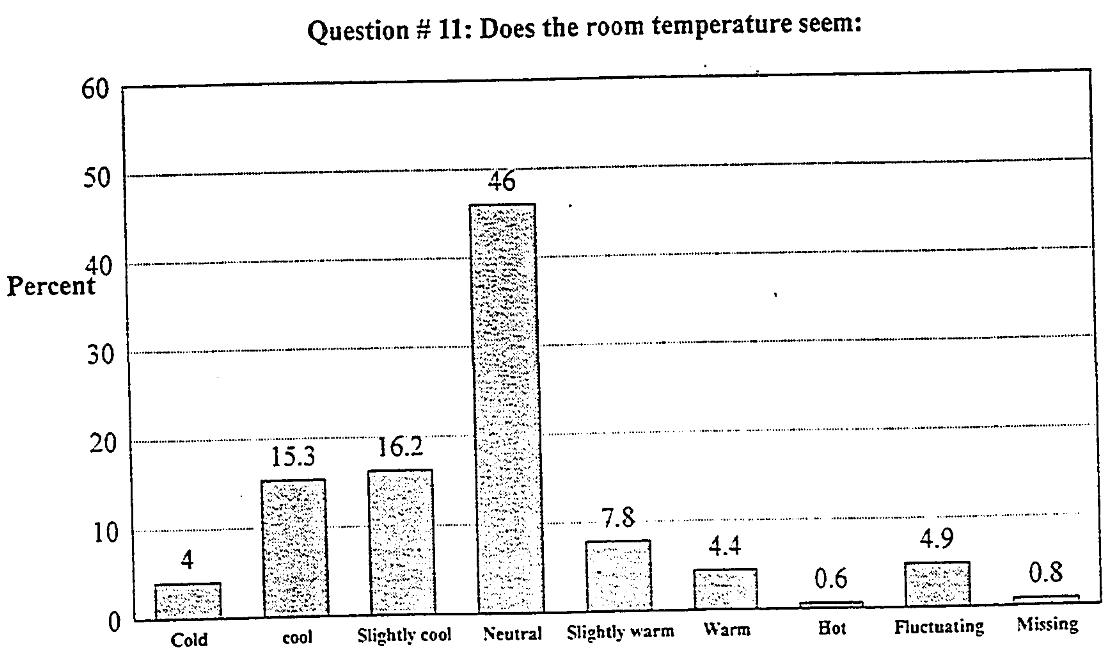


Figure 24 : Room Temperature

Percent of occupants	Air Humidity
2.5%	Very dry
17.2%	Dry
70.2%	Normal
8.7%	Humid
1%	Very Humid
0.4%	Missing

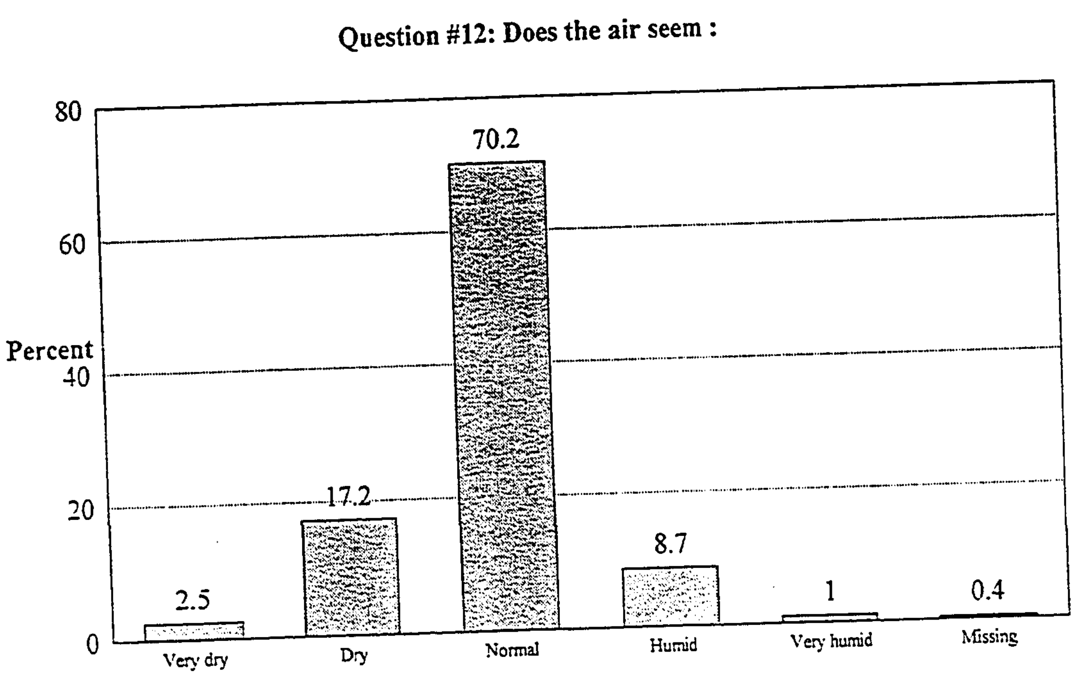


Figure 25 : Air Humidity

Percent of occupants	Windows availability
73.5	Yes
24.8	No
1.6	Missing

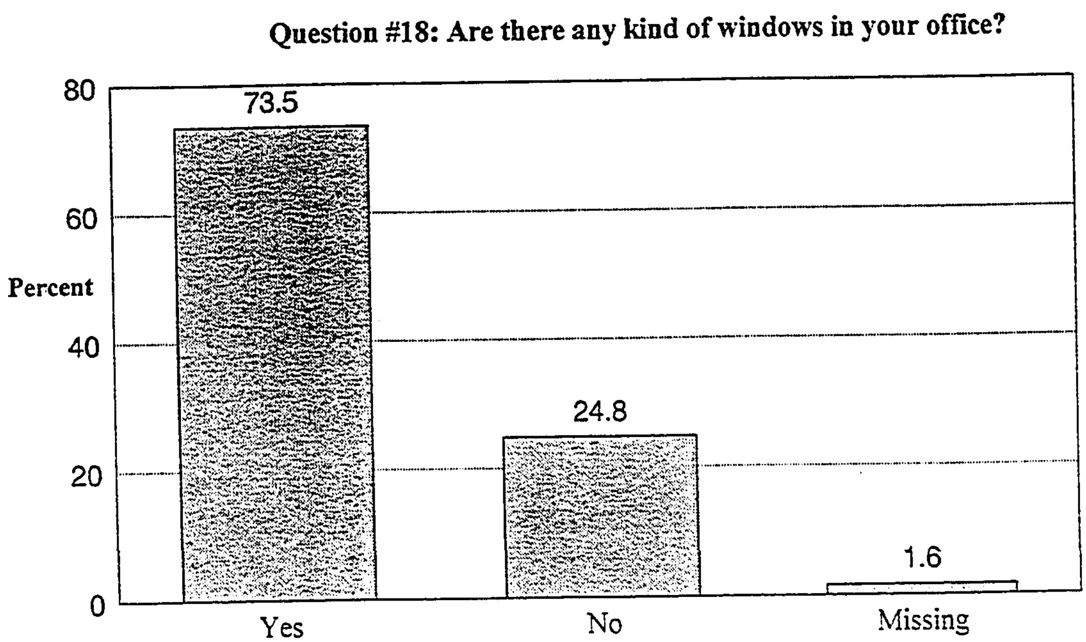


Figure 26 : Windows Availability

Percent of occupants	Windows orientation
11.3%	North
12%	East
9.1%	South
12.6%	West
5.7%	Northwest
3.1%	Northeast
3.2%	Southeast
2.9%	Southwest
13.4%	Corner
26.7%	Missing

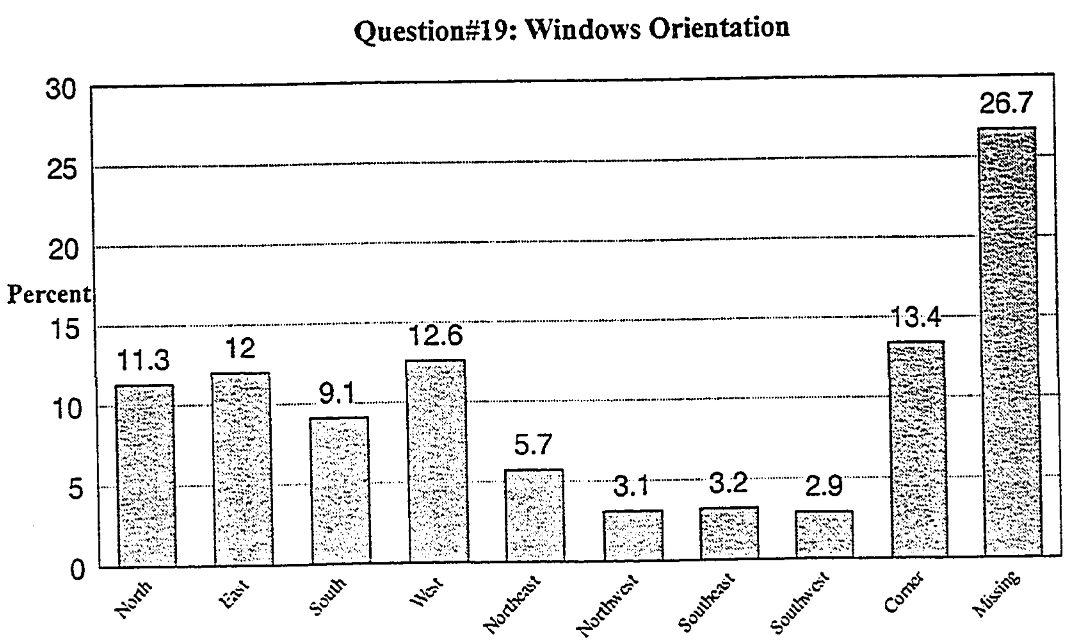


Figure 27 : Windows orientation

IAQ category: Four questions are included under this category, air clarity, odor intensity, odor sources, and dust accumulation. The purpose of these questions is to seek the respondents' response to the IAQ elements which they can sense and feel. Starting with the air clarity question (see Figure 28) 63.2 % of the respondents reported clear , 18.3% reported dusty and 17.3% smoky. It is noticed that the last two percentages are close, even though it might be expected that the dusty percentage should be higher due to the dusty environment we have. These give a strong indication that smoking is an important IAQ factor that should be considered the same way as dust.

The second factor to consider in this category is odor intensity. From the chart presented in Figure 29 (question # 16), it shows that 34% reported no odor , 38.9% reported slight odor and 25% reported odor ranging from moderate to over powering.

The sources of these odors is investigated in question # 17. From the chart of this question (Figure 30), it is indicated that cigarette smells have the highest percentage (25.4%). This reflects the role of smoking as a major indoor air pollutant. The unreported answers for this question is 23%, mainly because respondents that did not notice any smells skipped answering this question. The next highest percentage is 21.1% for respondent who reported a combination of odor sources (more than one source was selected).

The third factor in this category is dust accumulation on furniture. The purpose of this question is to have another measure of judging the dust in the room and to measure the level of custodial services. From the chart (see Figure 31) 30% reported moderate and too much dust accumulation.

Physical category: Two questions lay under this category, lighting level , and noise level. Figures 32 and 33 represent the response of the occupants to these questions. For the lighting question, 82% reported a satisfactory lighting level. Low lighting level was reported by 13%. Only 4.4 % of the respondents reported an intense lighting level.

Percent of occupants	Air Clarity
63.2%	Clear
18.3%	Dusty
17.3%	Smoky
1.1%	Missing

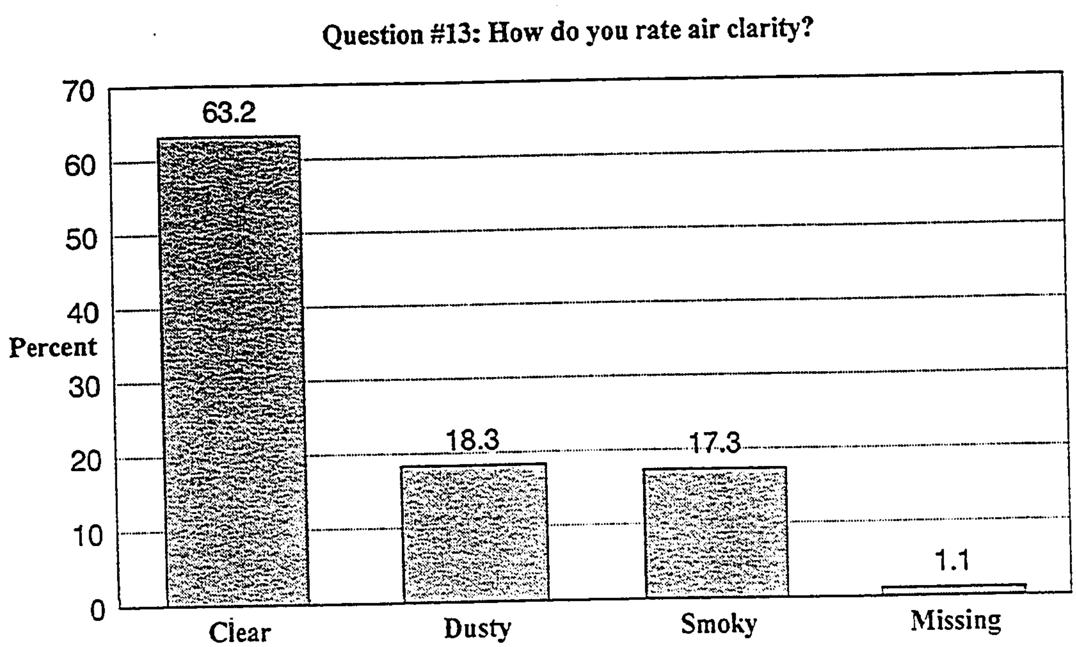


Figure 28 : Air clarity

Percent of occupants	Odor Strength
34.5%	No odor
38.9%	Slight odor
15.9%	Moderate odor
4.7%	Strong odor
2.2%	Very strong odor
2.1%	Overpowering odor
1.8%	Missing

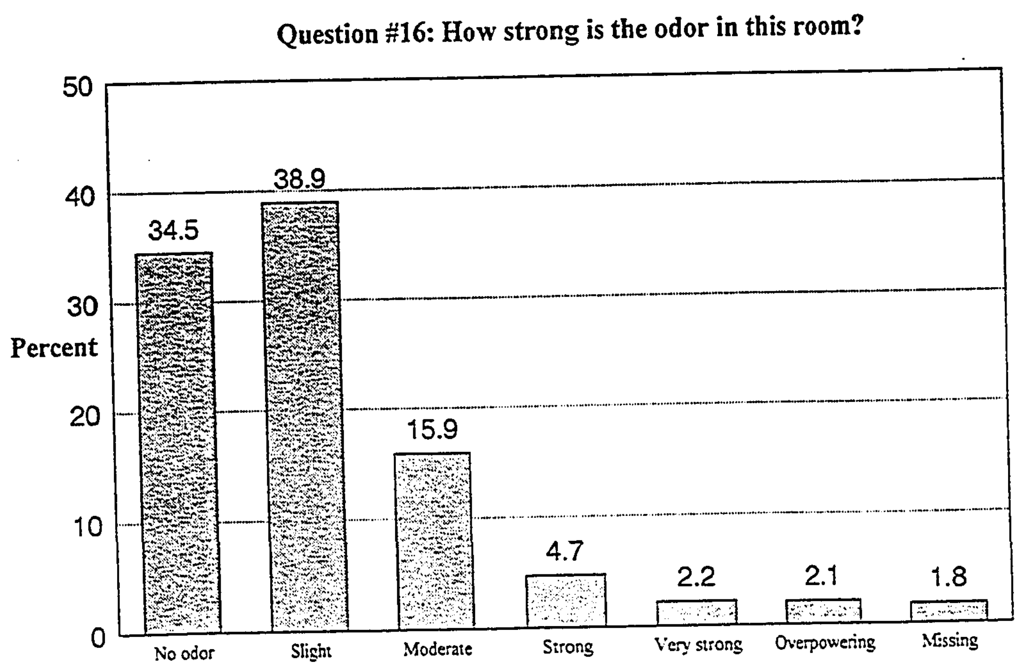


Figure 29 : Odor strength

Percent of occupants	Odor source
7.2%	Body odor
3.8%	Toilet odor
1.8%	Food smells
25.4%	Cigarette smells
1%	Car exhaust
8.3%	Furniture smells
8.4%	Dust smells
21.1%	Combination of smells
23.1%	Missing

Question #17: In your opinion, the odors in this room is mostly ....

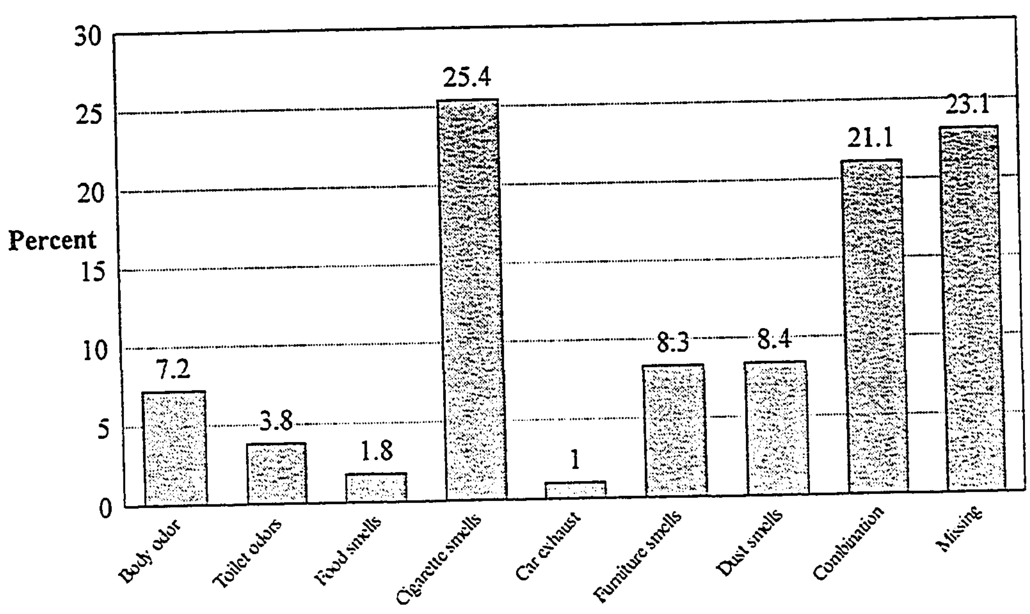


Figure 30 : Odor Sources

Percent of occupants	Dust accumulation
41%	Very little
28.1%	little
20%	Moderate
10.1%	Too much
0.8%	Missing

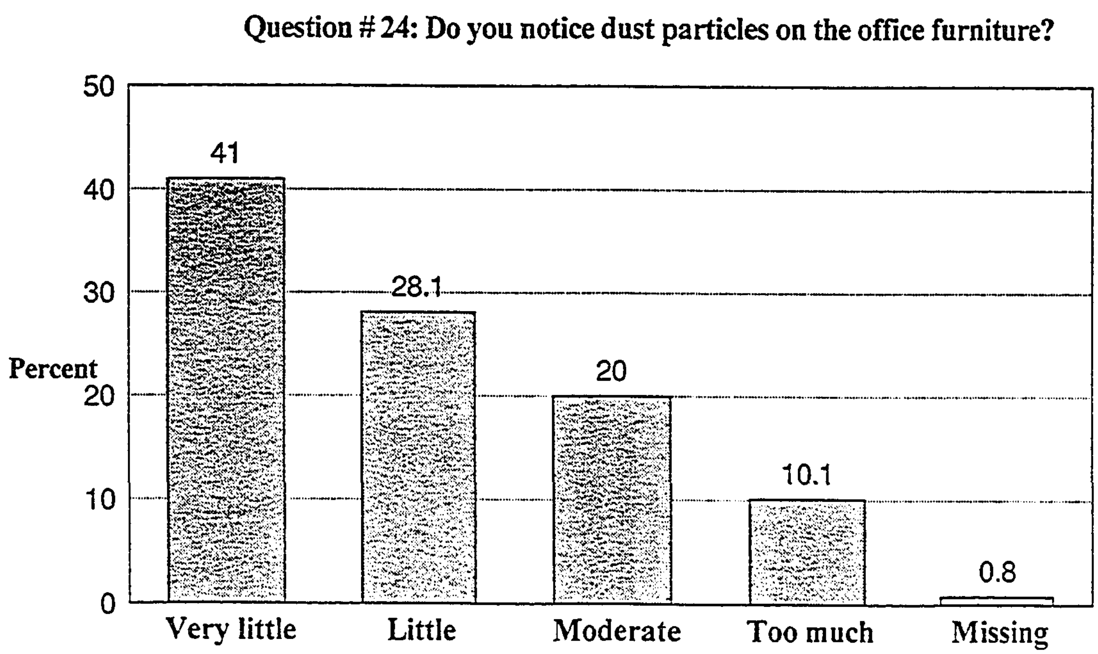


Figure 31 : Dust Accumulation on furniture

Percent of occupants	Noise level
16.8%	Very quite
49.8%	Moderately quite
27.7%	Noisy
4.4%	Very noisy
1.3%	Missing

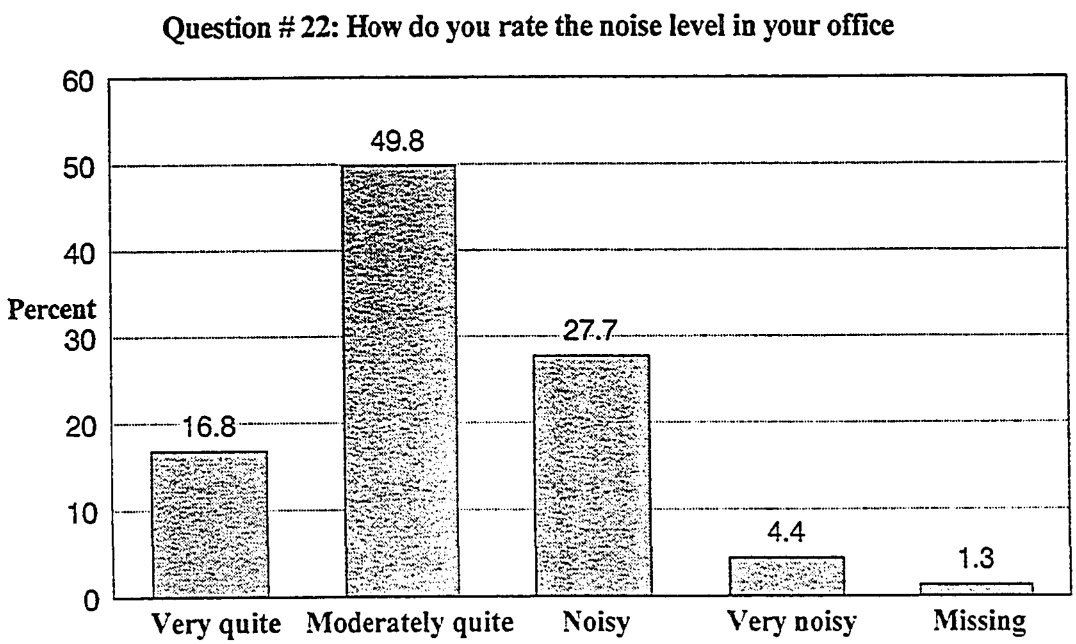


Figure 32 : Noise Level

Percent of occupants	Lighting level
13.1%	low
82.2%	Satisfactory
4.4%	Intense
0.4%	Missing

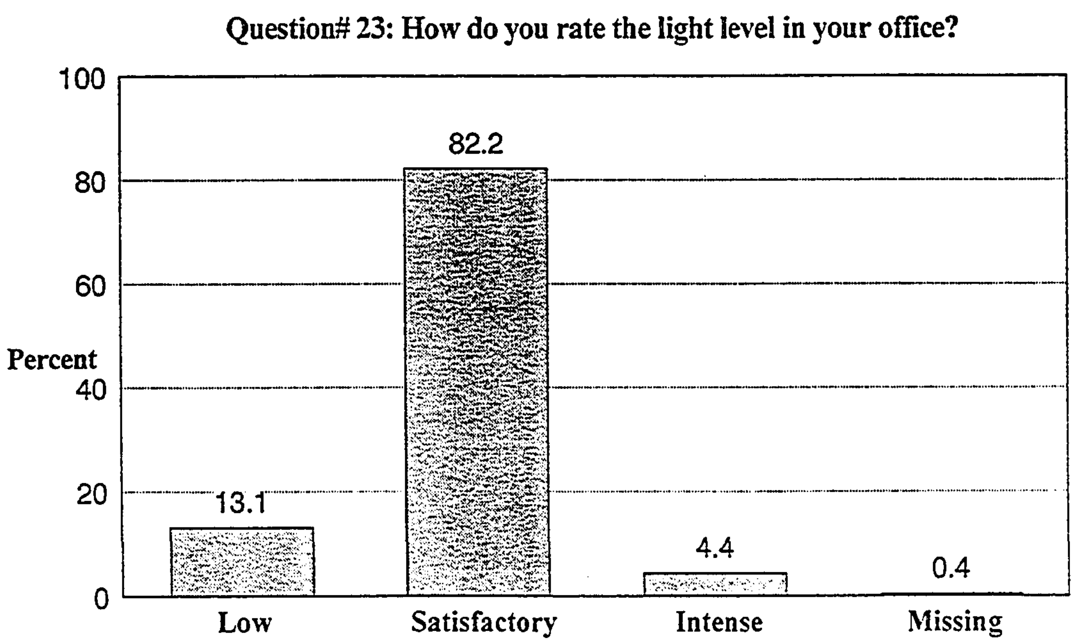


Figure 33 : Lighting Level

Symptoms category: This category has only one question about the symptoms that the occupants might have suffered during their occupancy. The respondents were asked to report the frequency of suffering these symptoms on a four point scale (1-Never , 2 Seldom, 3 Sometimes, and 4 Often). In order to summarize all the symptoms reported by each respondent a mathematical index called the Reported Symptoms Index (RSI) was created. Figure 34 presents the mathematical calculation procedure that has been followed in achieving the RSI. The lower the RSI the lower the frequency of experiencing the symptoms and the reverse is also true. Figure 35 presents the RSI ranges reported by the respondents.

25-Have you Experienced any of the following symptoms while working in this space?

	1	2	3	4
Headache	❑ Never	❑ Seldom	❑ Sometimes	❑ Often
Heavy head	❑ Never	❑ Seldom	❑ Sometimes	❑ Often
Eye Irritation	❑ Never	❑ Seldom	❑ Sometimes	❑ Often
Nose Irritation	❑ Never	❑ Seldom	❑ Sometimes	❑ Often
Throat Irritation	❑ Never	❑ Seldom	❑ Sometimes	❑ Often
Dry mouth	❑ Never	❑ Seldom	❑ Sometimes	❑ Often
Shortness of breath	❑ Never	❑ Seldom	❑ Sometimes	❑ Often
Chest pains	❑ Never	❑ Seldom	❑ Sometimes	❑ Often
Nausea	❑ Never	❑ Seldom	❑ Sometimes	❑ Often
Fatigue	❑ Never	❑ Seldom	❑ Sometimes	❑ Often
Drowsiness	❑ Never	❑ Seldom	❑ Sometimes	❑ Often
Difficulty in Concentration	❑ Never	❑ Seldom	❑ Sometimes	❑ Often
Dry skin	❑ Never	❑ Seldom	❑ Sometimes	❑ Often
	X	Y	Z	O

X=Σ" Never" , Y=Σ" Seldom" , Z=Σ" Sometimes" , and O=Σ" Often"

RSI = ((X*1) + (Y*2) + (Z* 3) + (O*4)) /10 RSI scale 1.3.................3.2..............5.2

Min. Ave. Max.

Figure 34 : Reported Symptoms Index (RSI) calculation method (Kohout,1974)

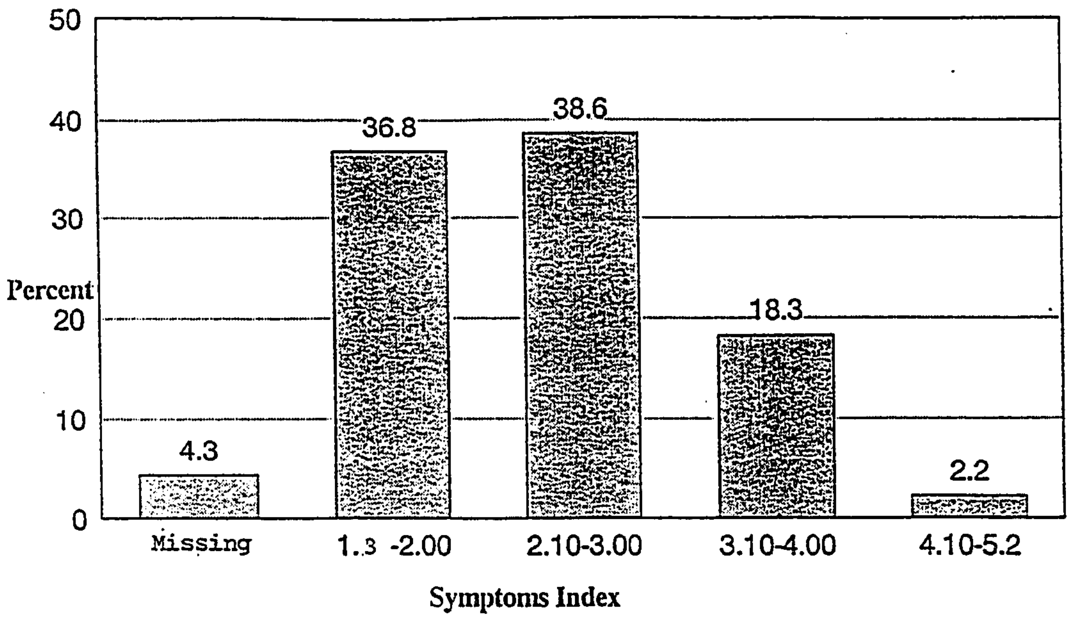


Figure 35 : Ranges of RSI for the respondents

Other questions: Some questions in the occupants' questionnaire were not appropriate under any of the previously mentioned categories. Therefore these questions will be discussed separately in the following sections.

Question # 8 is about the rating of productivity after moving to the building . From the chart of this question in Figure 36, 44.7% of the respondents reported no change of productivity and 45.6% reported improvement of their productivity after moving to the building. Around 8% reported a decline in productivity and because of that, this question is considered irrelevant.

Question # 10 is about feeling relieved when leaving the building. From the chart of this question in Figure 37, 65% of the respondent reported they feel relieved when leaving the building and 29% reported No. In order to utilize this question and to see whether the indoor environment has contributed to this feeling, the result of this questions has to be analyzed with other categories.

Question # 14 is about rating the air movements. The chart of this question in Figure 38 shows that 5.5 % of the respondents reported drafty air movement. Due to this low percentage the effect of air movement is not relevant.

Percent of occupants	Productivity
44.7%	Same as before
45.6%	Better
7.9%	Worse
1.8%	Missing

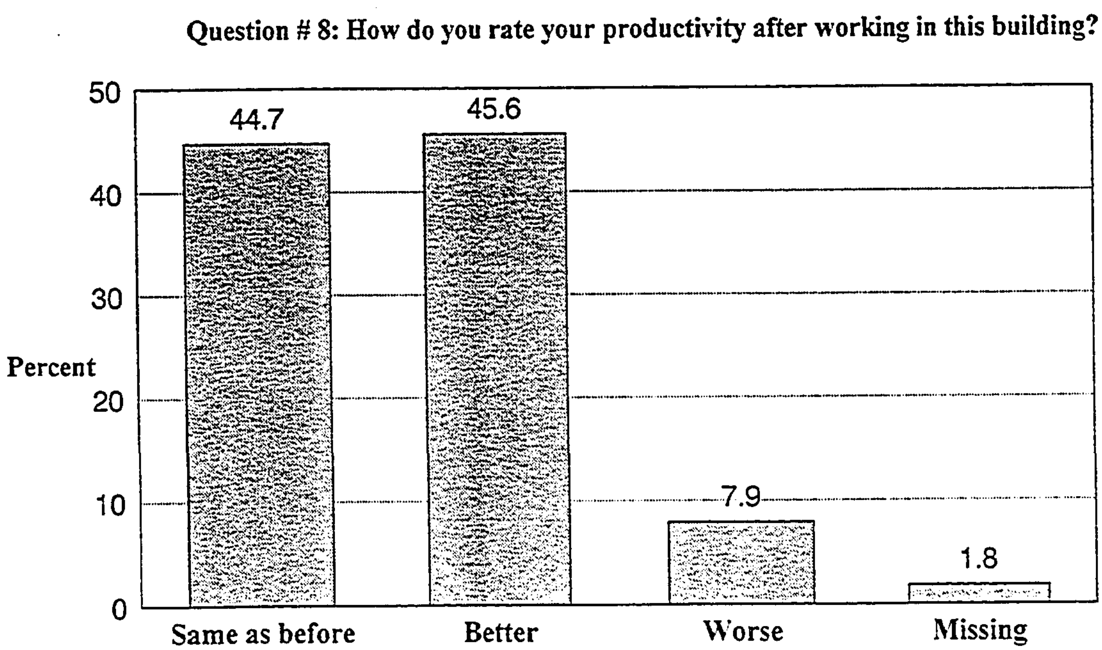


Figure 36 : Productivity after work in the building

Percent of occupants	Relived when leaving the building
65.9%	Yes
28.4%	No
5.7%	Missing

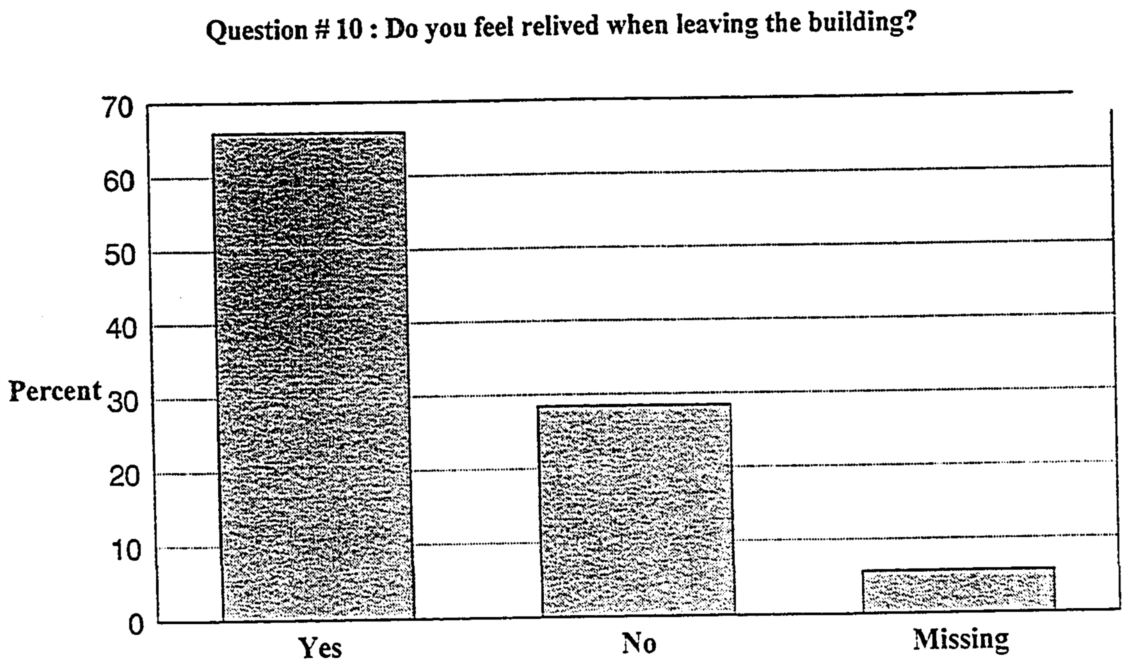


Figure 37 : Relived when leaving the building

Percent of occupants	Air Movement
35.4%	Still air
57.6%	Little movement
5.5%	Drafty
1.4%	Missing

Question # 14: How do you rate air movement?

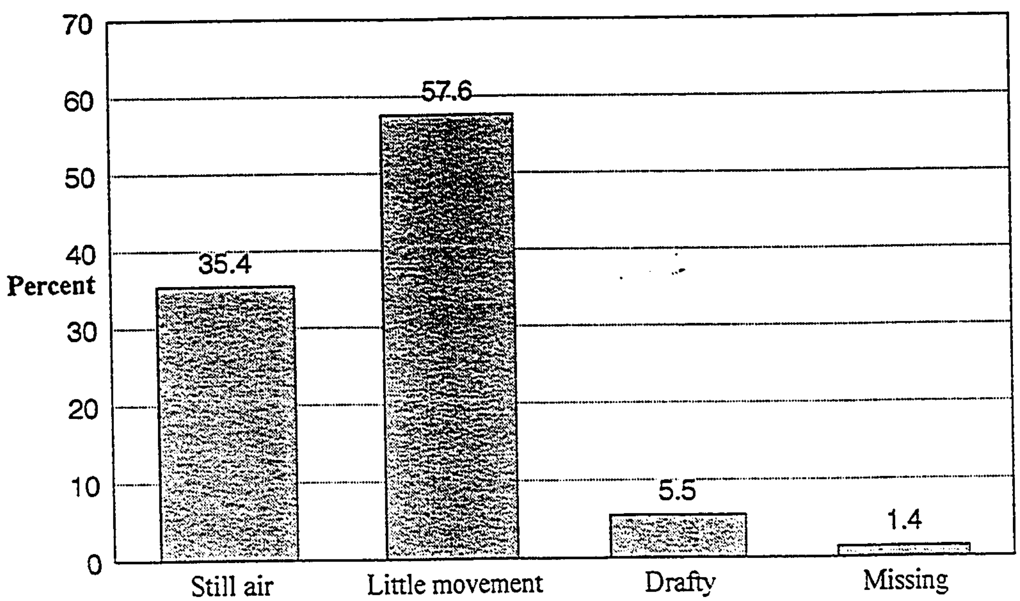


Figure 38 : Air movement

Question # 15 is about the sensation of air on the respondents body. The chart for this question presented in figure 39 shows that the highest percentage reported feeling the air on the face (40.2 %). Also 17% of the respondents did not answer this question, probably because they have not sensed the air movement in a any of the provided answers. Some of the respondents chose more than one part of the body; therefore, their answers have been grouped under "All over". 7.5 % of the respondents lay under this group. In order to utilize this result, it has to be analyzed with the symptoms reported by the respondents.

Question #26 and #27 (see figure 40 and 41) are a bout the reduction in productivity due to the reported symptoms and the absenteeism caused by these symptoms. The purpose of these questions is to measure the effect of these symptoms on the general productivity of the respondents. From the chart of question # 26 it can be seen that 63.4% of the respondents answered Never and Seldom. 34% answered Sometimes and Often. This chart clearly indicates the effect of the experienced symptoms in the work place. From the chart for question # 27 , we can see that 81% of the respondents answered Never and Seldom. Only 15% of the respondents answered Sometimes and Often. In comparing the result of this question with question # 26, it is found that the reported Sometimes and Often of question # 27 is much lower than the reported answers for # 27. This is mainly due to the strict office hours in the private sector which most of the occupants belong to.

Finally, question # 28 (see Figure 42) which is about the final opinion of the respondents about the provided work environment. Around 59% of the respondents reported that they are comfortable in their offices. 31% reported that they are comfortable in their offices but they desire some changes to be made. Only 6% of the respondents reported that they are not comfortable and they want to change.

4.2.4.3 Building Survey Summary:

This survey covers thirty buildings which is the outcome of stage 4 of the distribution and collection process mentioned earlier. The purpose of this survey is to gather the buildings system IAQ related information based on the identified problems listed in Table 13.

Percent of Occupants	Air Sensation
40.2%	Face
15.9%	Back of the neck
8.5%	Hands
10.7%	Feet
7.5%	All over
17.1%	Missing

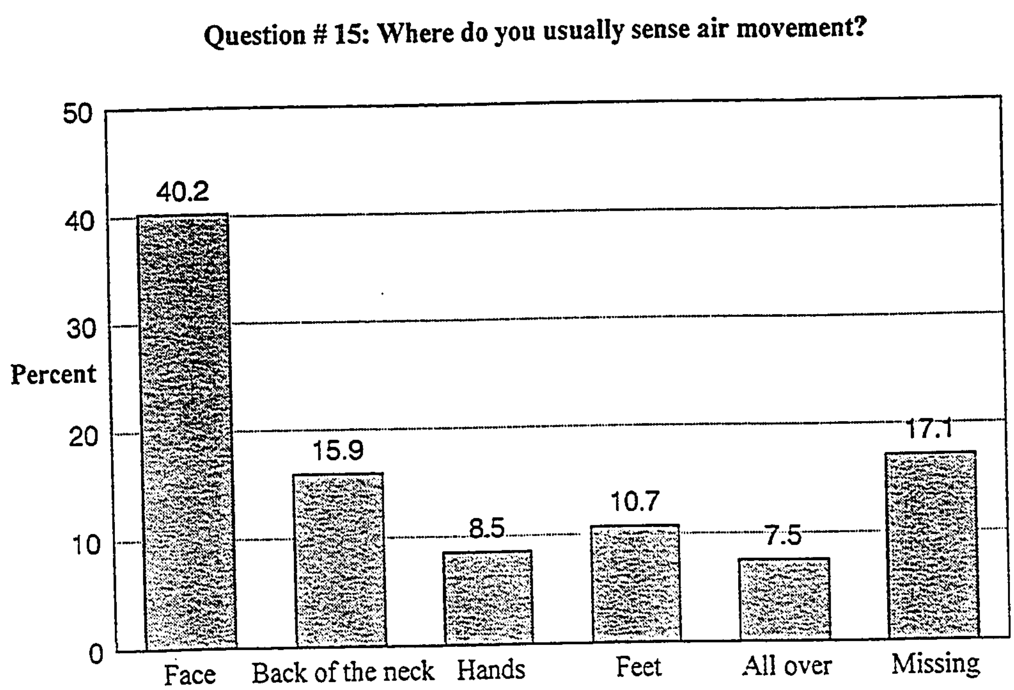


Figure 39 : Air Sensation

Percent of occupants	Reduction in work ability
38.4%	Never
25.0%	Seldom
28.1%	Sometimes
4.9%	Often
3.5%	Missing

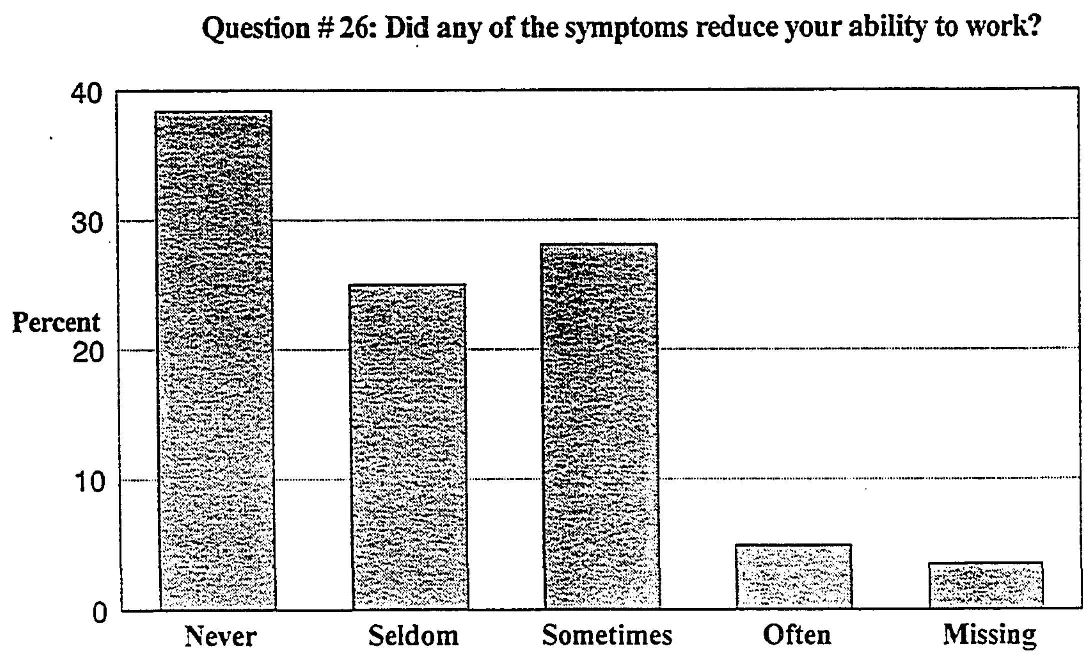


Figure 40 : Reduction in work ability

Percent of occupants	Absenteeism
61.1%	Never
19.8%	Seldom
13.8%	Sometimes
1.9%	Often
3.5%	Missing

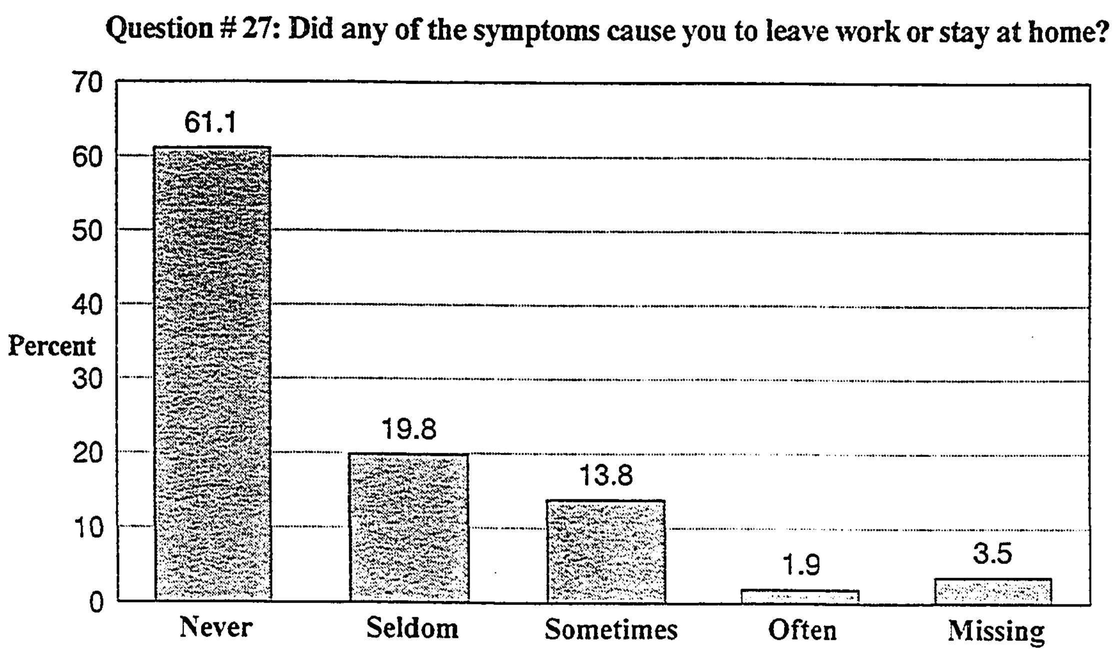


Figure 41 : Absenteeism

Percent of occupants	Final Opinion
58.9%	Comfortable
31%	Comfortable with changes
6%	Not comfortable
4.1%	Missing

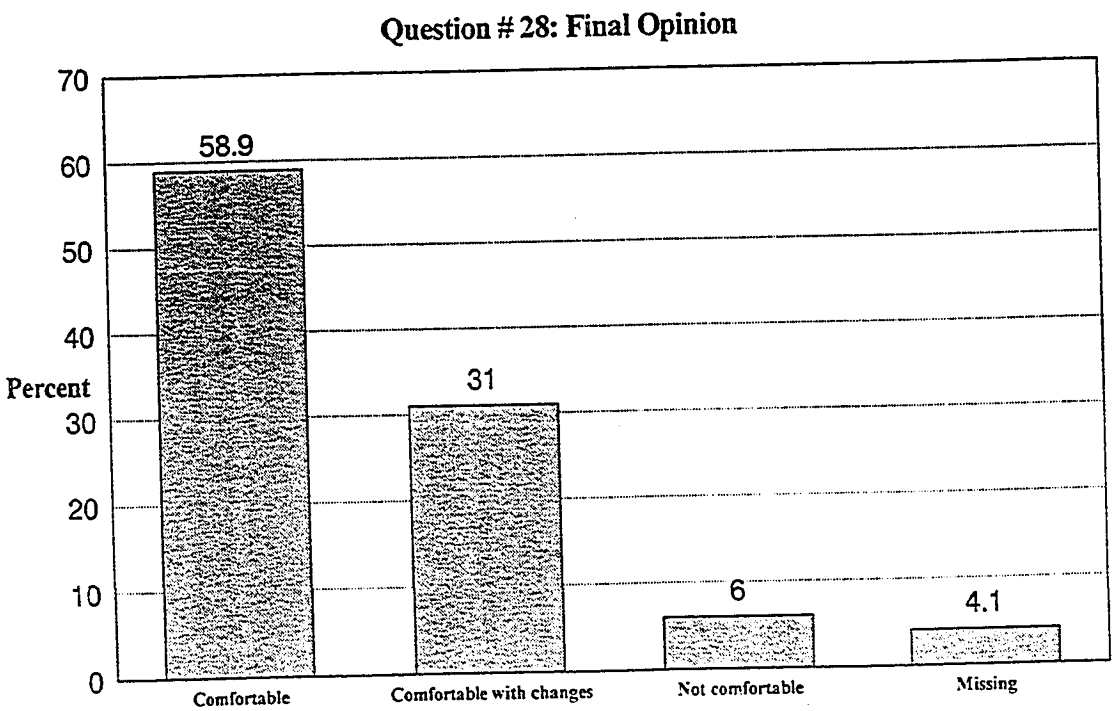


Figure 42: Final Opinion

The questionnaire for this survey has been classified into four categories: 1) Operation and maintenance 2) HVAC system 3) Architectural system 4) Indoor environment related complaints. The charts representing the results of this survey are presented below(see figures from Figure 43 to 72). The discussion of this result is done in details in the final analysis. The only exceptions to this are Questions # 2.1, about the type of HVAC system, and question # 2.5 about, the fresh air intake.

The HVAC systems found in the surveyed buildings can be summarized in four types : 1) all water systems 2) all air systems 3) combination of water and air systems 4) package unit systems. Therefore the result of question # 2.1 were presented interim of those systems.

The fresh air intake in the buildings (question # 2.5) could not be determined due to the following:

1- As built drawings were not available in most buildings. and when available no detailed sir balance diagrams which showed the air quantities exhausted and introduced into the building.

2- No records of testing and balancing for the HVAC system which showed the actual measurements of air quantities.

Building Age (Years)	Building Number
1	26
2	10
3	14,28
5	57
7	13,23,42
8	10,27
9	12,17
10	2,17,24,40
11	50
12	7,19,27,46
13	15
14	11,34,1
15	1,18,35,53,5
17	5
18	58

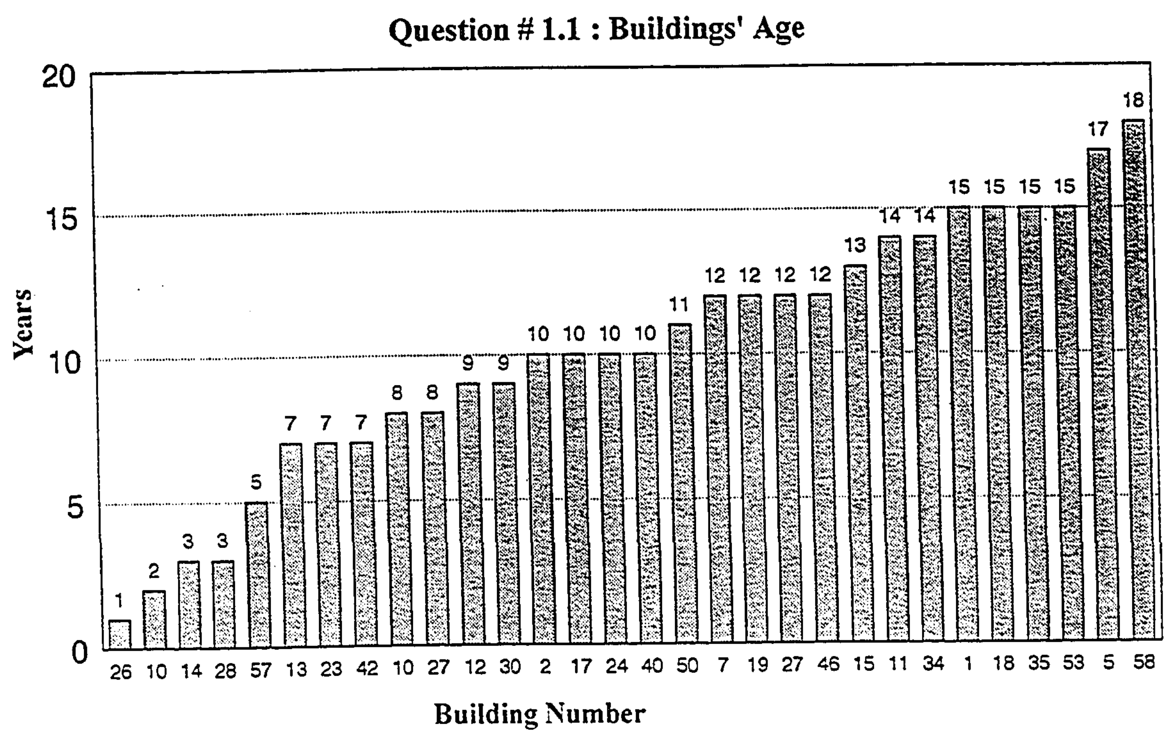


Figure 43 : Buildings' Age

Percent of Surveyed Buildings	O & M is performed by
56.7%	Self operation and maintenance
23.3%	One prime contractor
13.3%	Several contractors
6.7%	On call contractor

Question # 1.2 : Operation and maintenance is performed by....

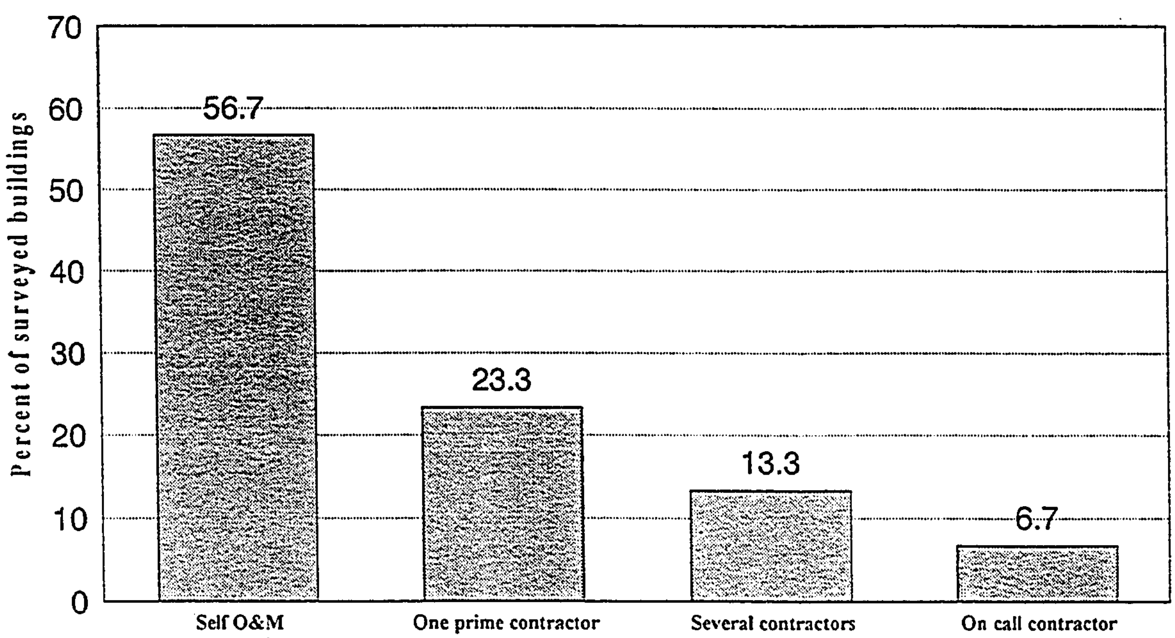


Figure 44 : Operation and Maintenance

Percent of surveyed buildings	Maintenance Pattern
30%	All corrective
20%	70% corrective
45%	50% corrective
5%	20% corrective

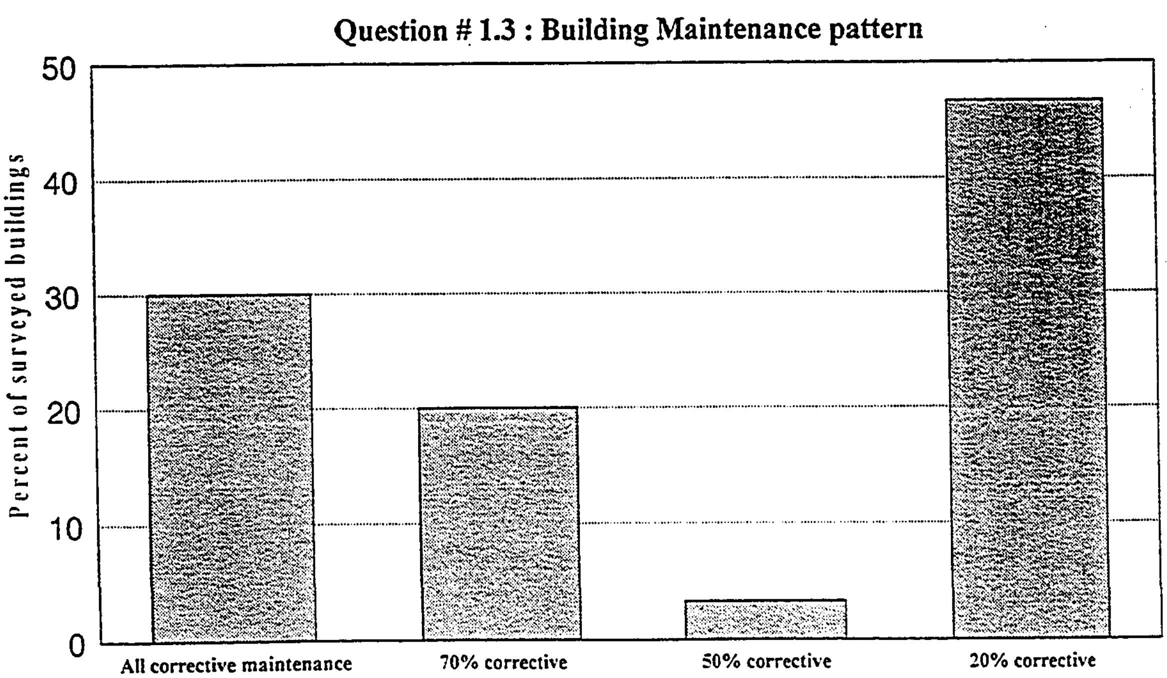


Figure 45 : Building Maintenance pattern

Percent of surveyed Buildings	Carpet Shampooing
60%	When requested
22%	Once a month
3%	Twice a month
15%	Missing

Question# 1.4 : How often do you shampoo carpets?

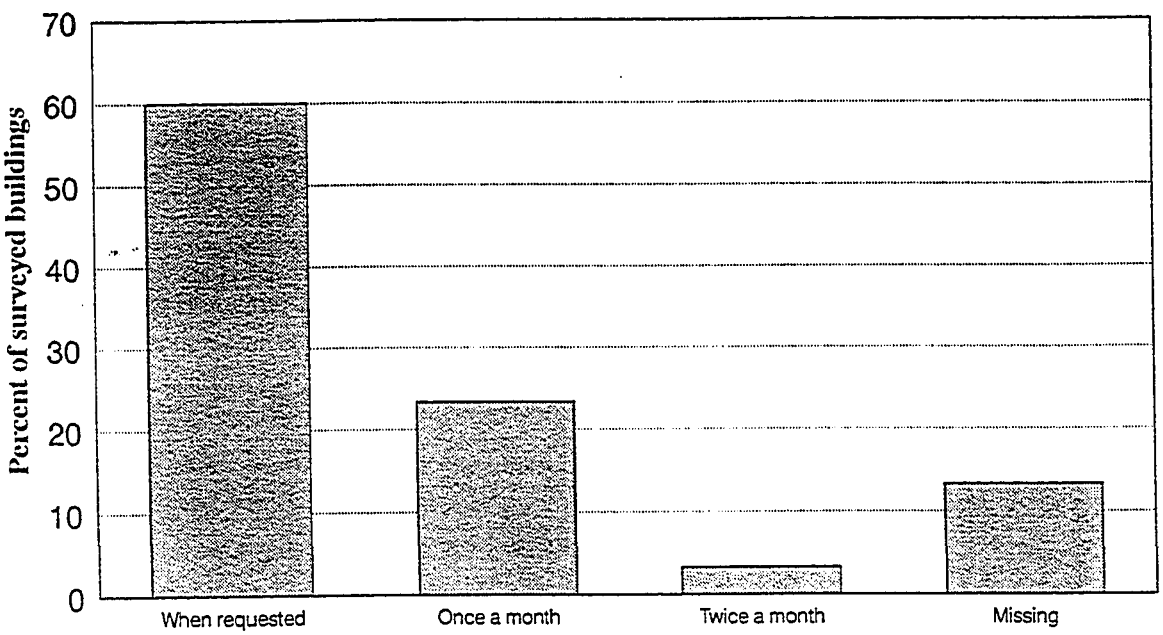


Figure 46 : Carpet Shampooing

Percent of Surveyed Buildings	Floor Cleaning
4%	Once a week
11%	Every other day
85%	Daily

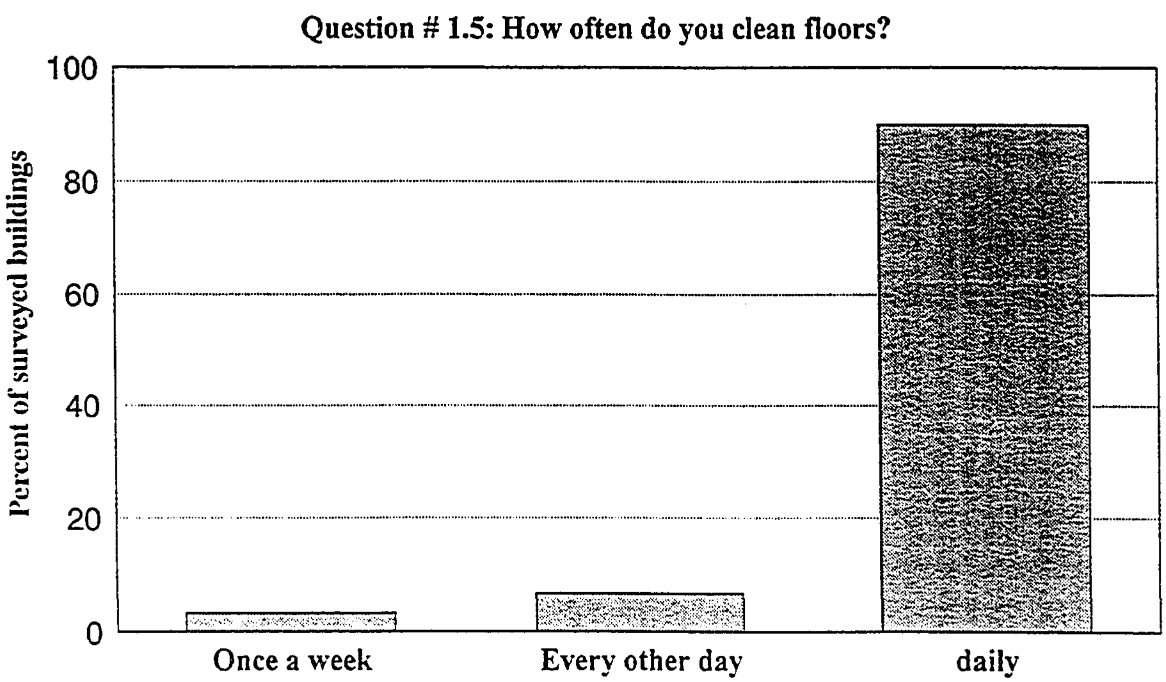


Figure 47 : Floor Cleaning

Percent of Surveyed Buildings	O& M manuals availability
30%	Not available
20%	Partially available
50%	Available

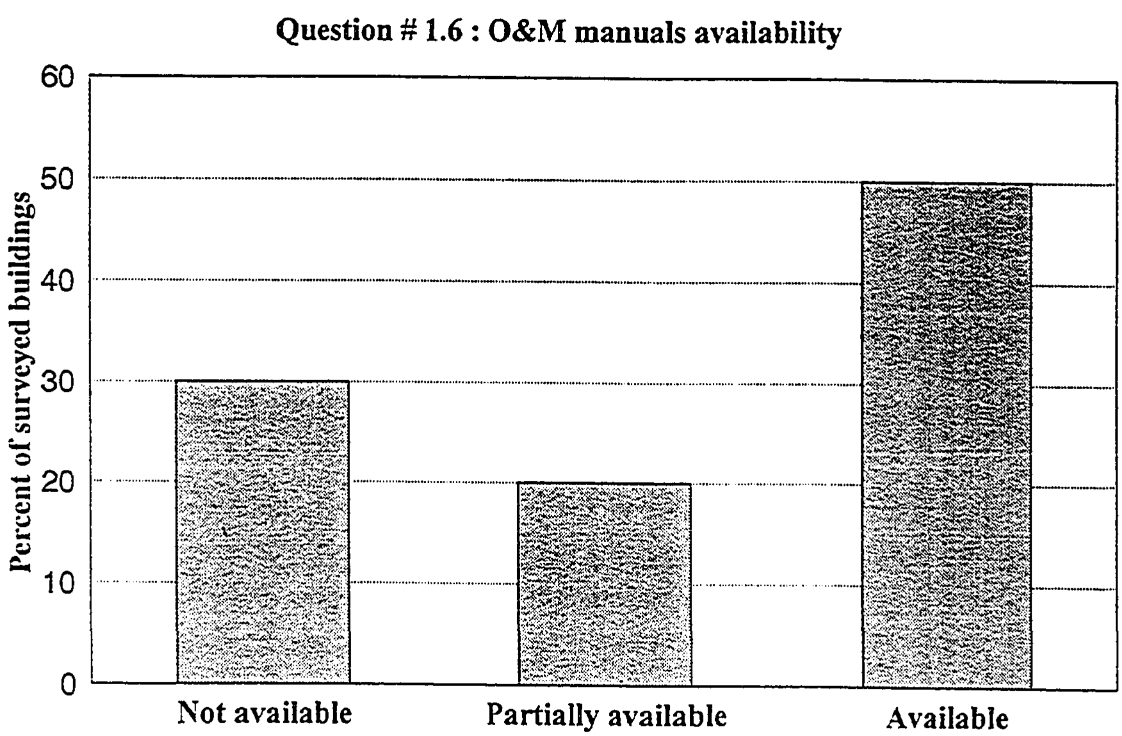


Figure 48 : O&M manuals availability

Percent of surveyed Buildings	As built drawings availability
32%	Not Available
18%	Partially Available
50%	Available

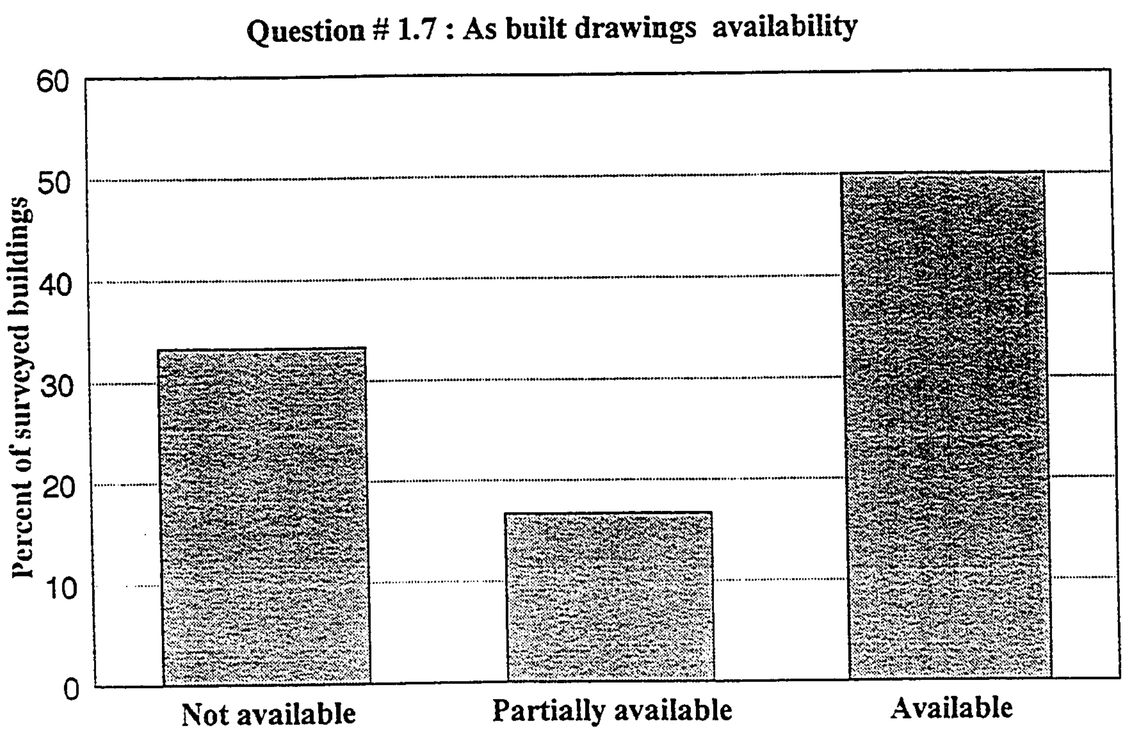


Figure 49 : As built drawings availability

Percent of Surveyed Buildings	Pest control use
53%	Yes
33%	No
34%	Missing

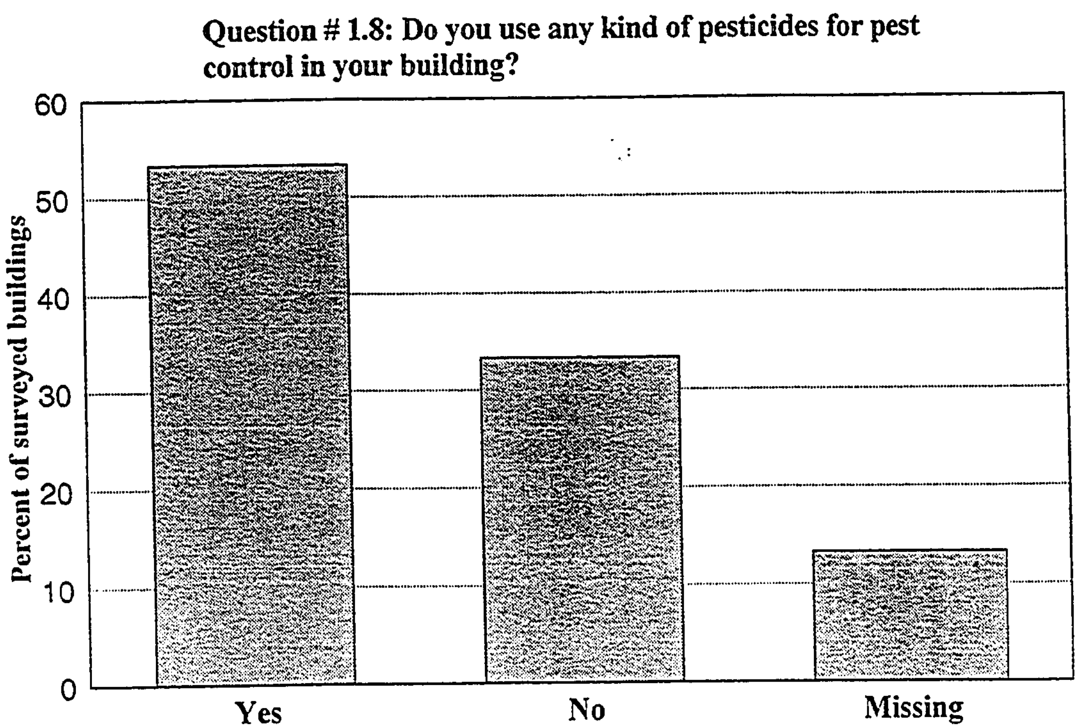


Figure 50 : Pest control use

Percent of surveyed Buildings	HVAC system
25%	All water systems
27%	Air & water systems
26%	Package units
20%	All air system

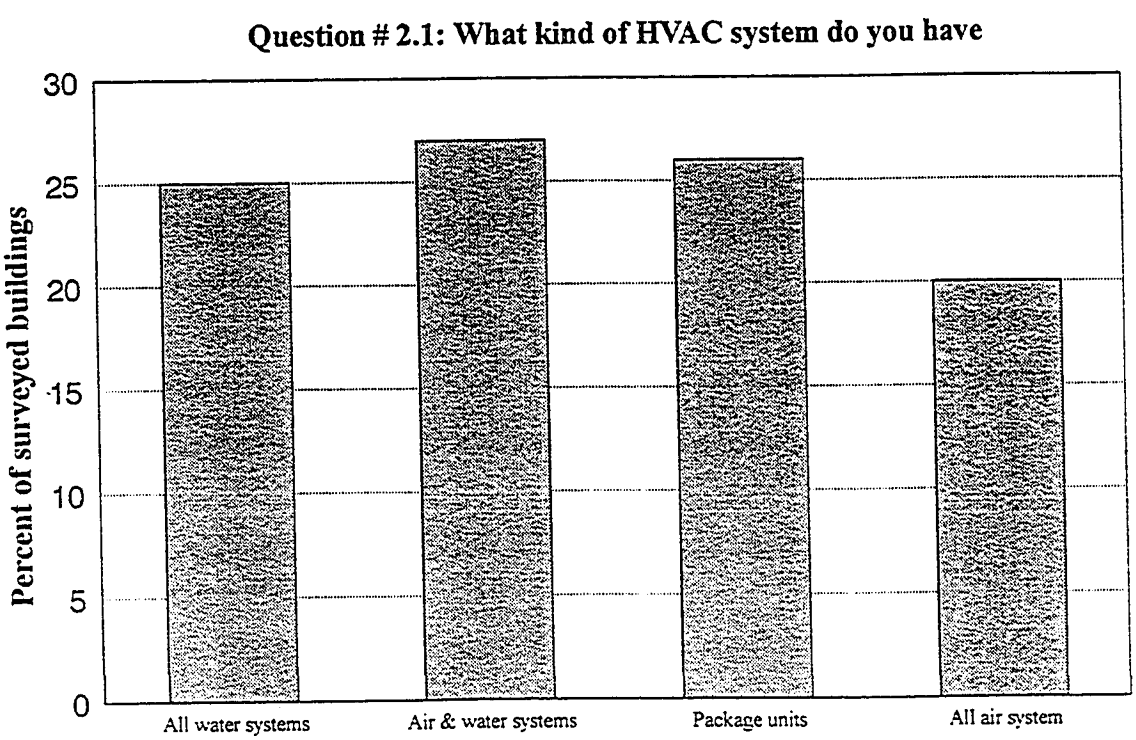


Figure 51 : HVAC system

Percent of Surveyed Buildings	Ducting Material
80%	Galvanized steel
18%	Fiberglass
2%	Both

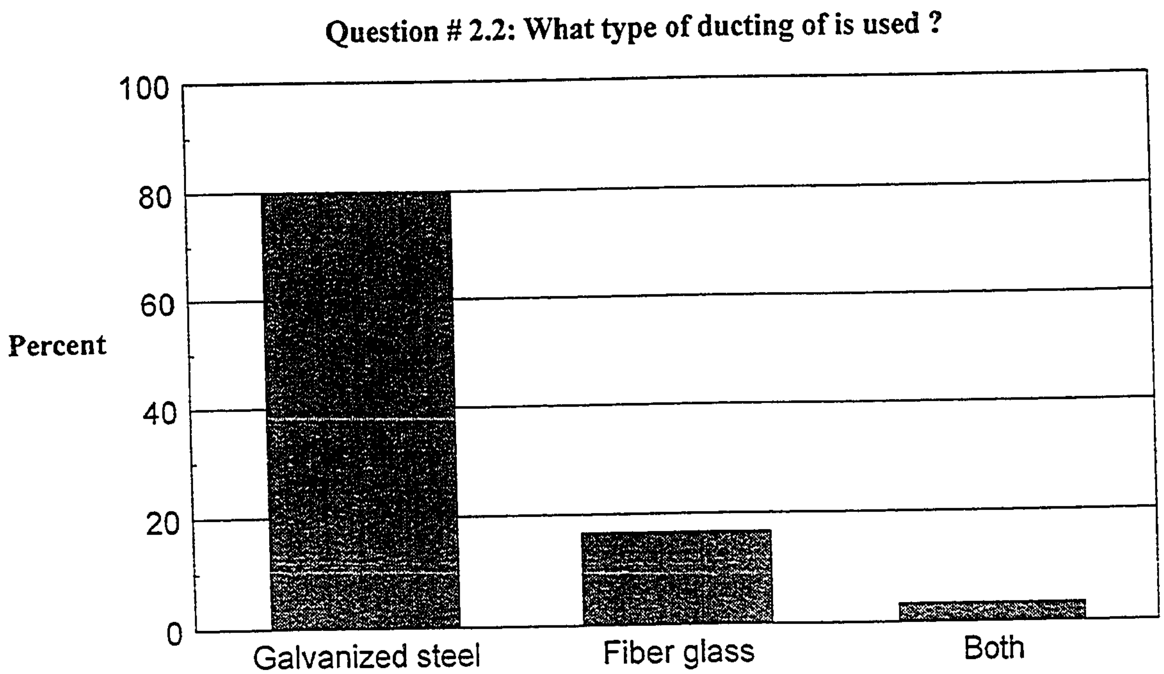


Figure 52 : Ducting Material

Percent of surveyed Buildings	Filter type
4%	Panel (greased)
88%	Panel (dry)
4%	Moving curtain (greased)
4%	Moving curtain (dry)

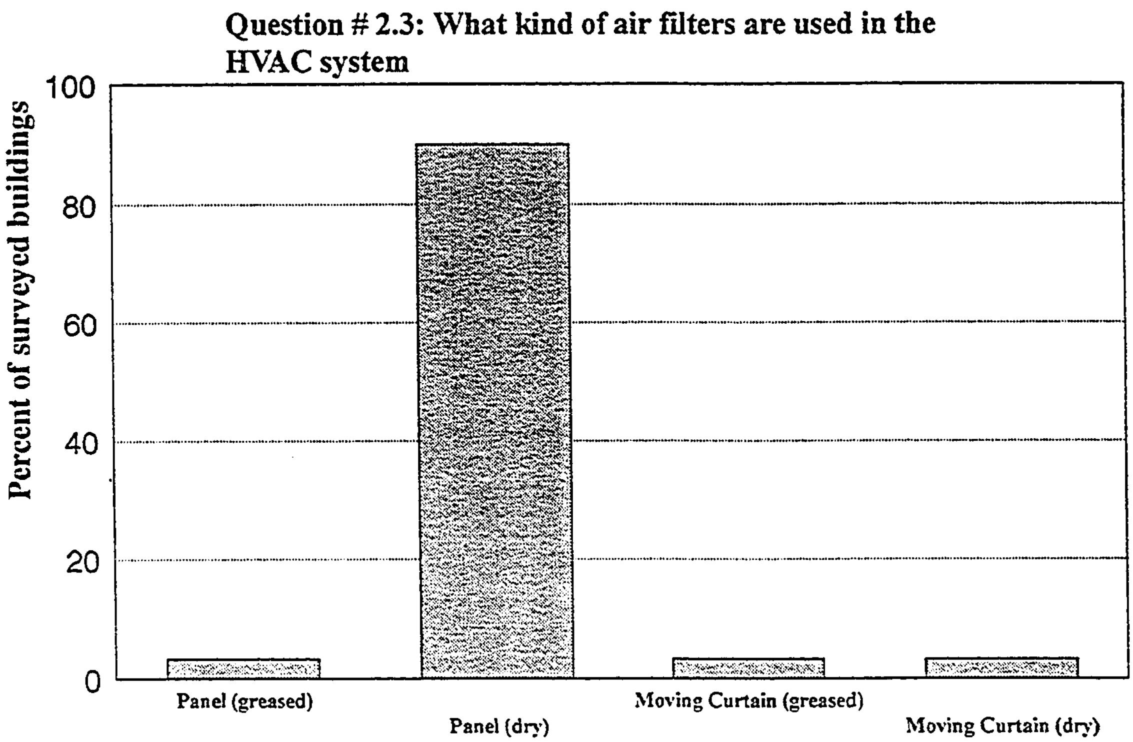


Figure 53 : Filter type

Percent of Surveyed Buildings	Economizer Cycle
98%	No
2%	Yes

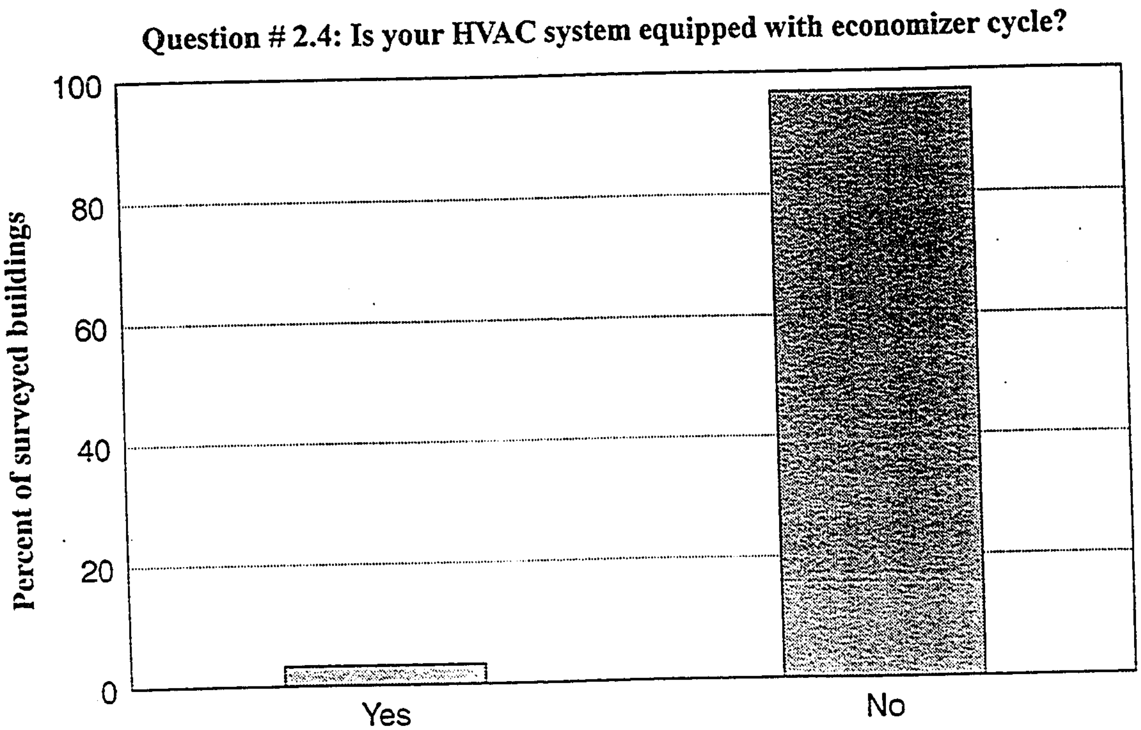


Figure 54 : Economizer cycle

Percent of surveyed Buildings	HVAC system Calibration
67%	None
10%	Once
13%	Twice
10%	After renovation

Question # 2.6 : Have you performed any HVAC system calibration and balancing since the occupation date?

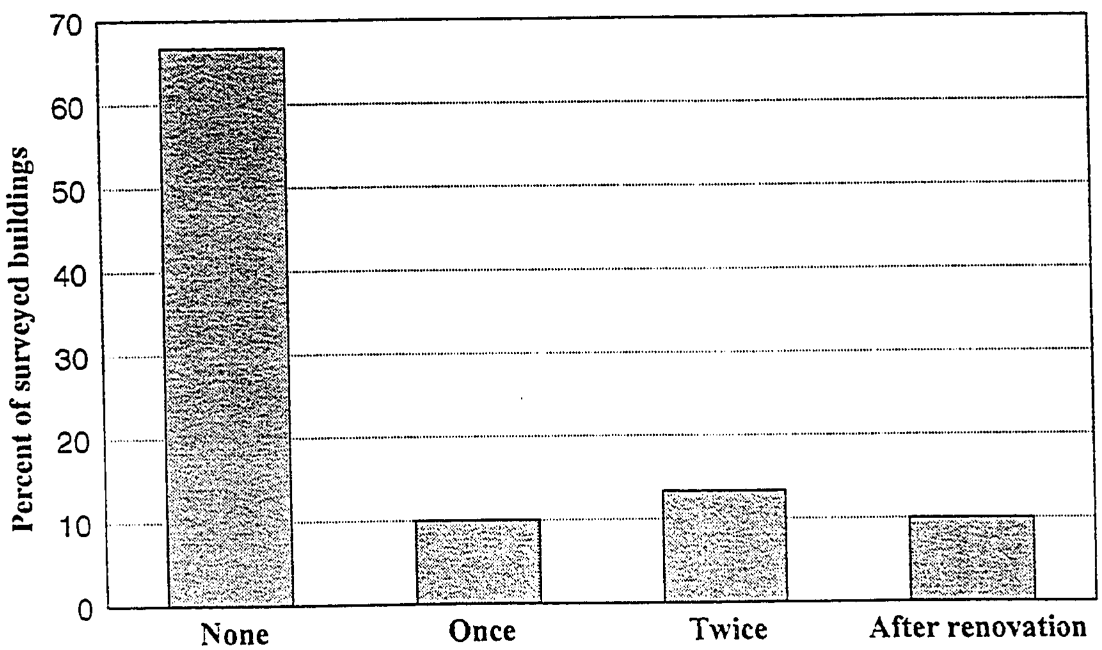


Figure 55 : HVAC system Calibration

Percent of surveyed Buildings	Duct Cleaning
73%	None
10%	Once
3%	Twice
7%	Three times
7%	Missing

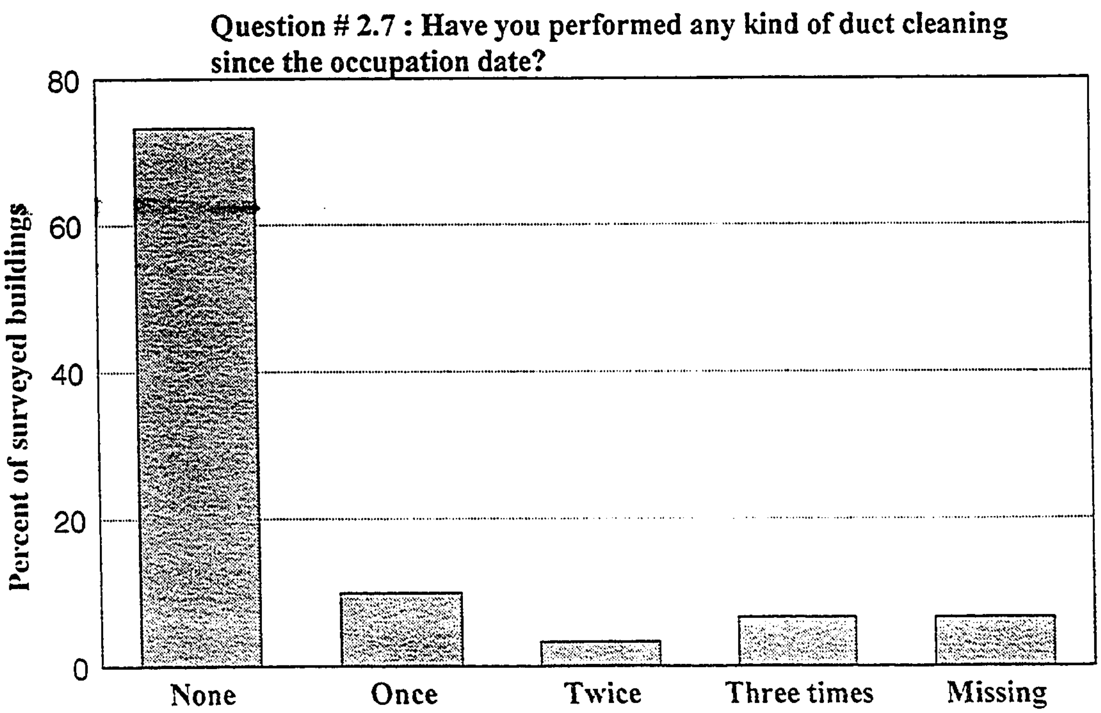


Figure 56 : Duct Cleaning

Percent of Surveyed Buildings	HVAC Preventive Maintenance
13%	None
41%	Once a year
17%	Twice a year
3%	Three times a year
24%	Four times a year
2%	Missing

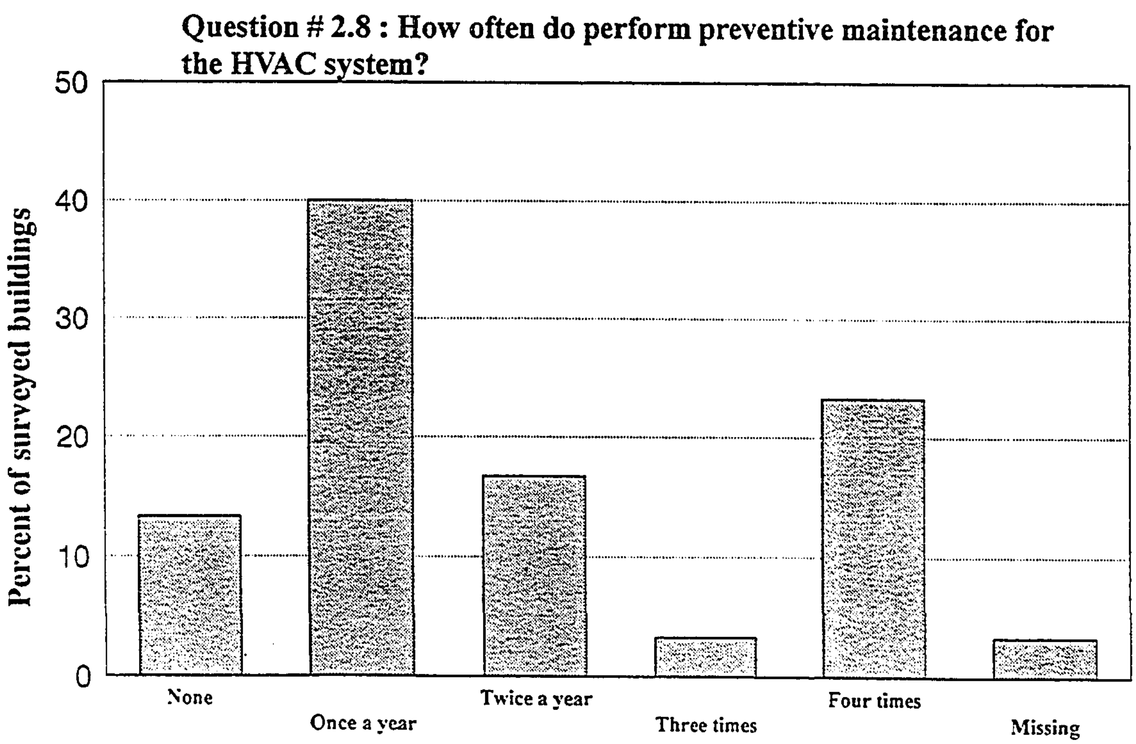


Figure 57: HVAC Preventive Maintenance

Percent of Surveyed Buildings	HVAC Operational Modes
56%	24 hours
18%	Office hours only
26%	2 hours earlier

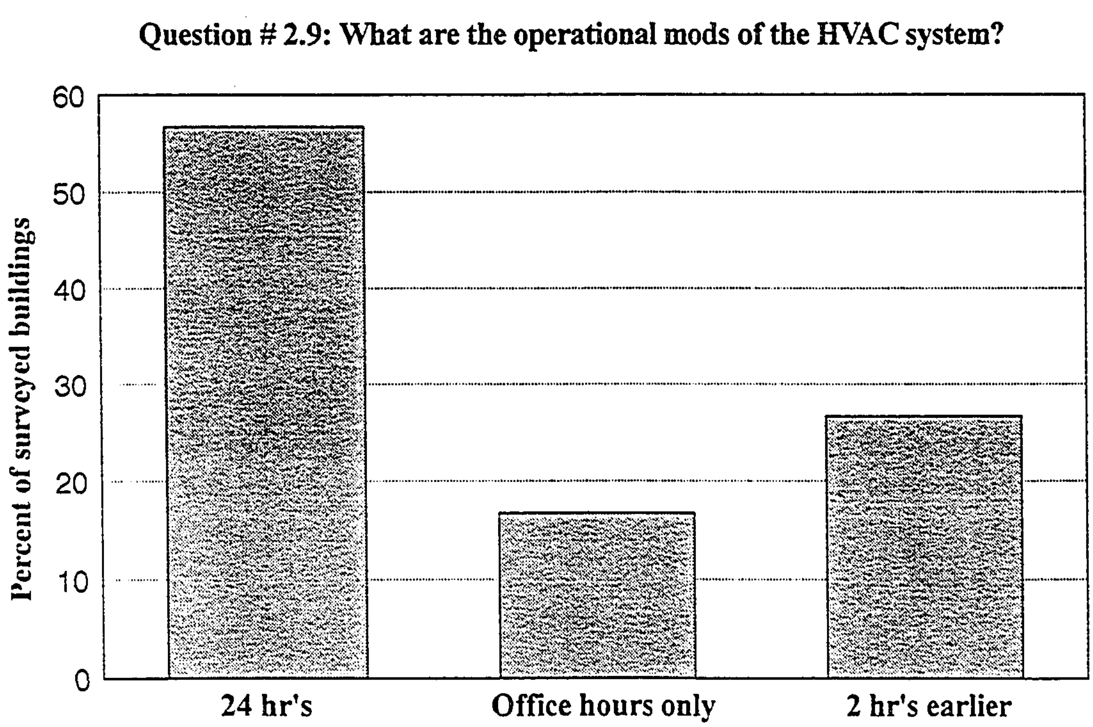


Figure 58 : HVAC Operational Mod

Percent of Surveyed Buildings	Refrigeration equipment location
66%	On the roof
17%	outdoor
7%	Indoor
7%	Indoor & Outdoor
3%	Missing

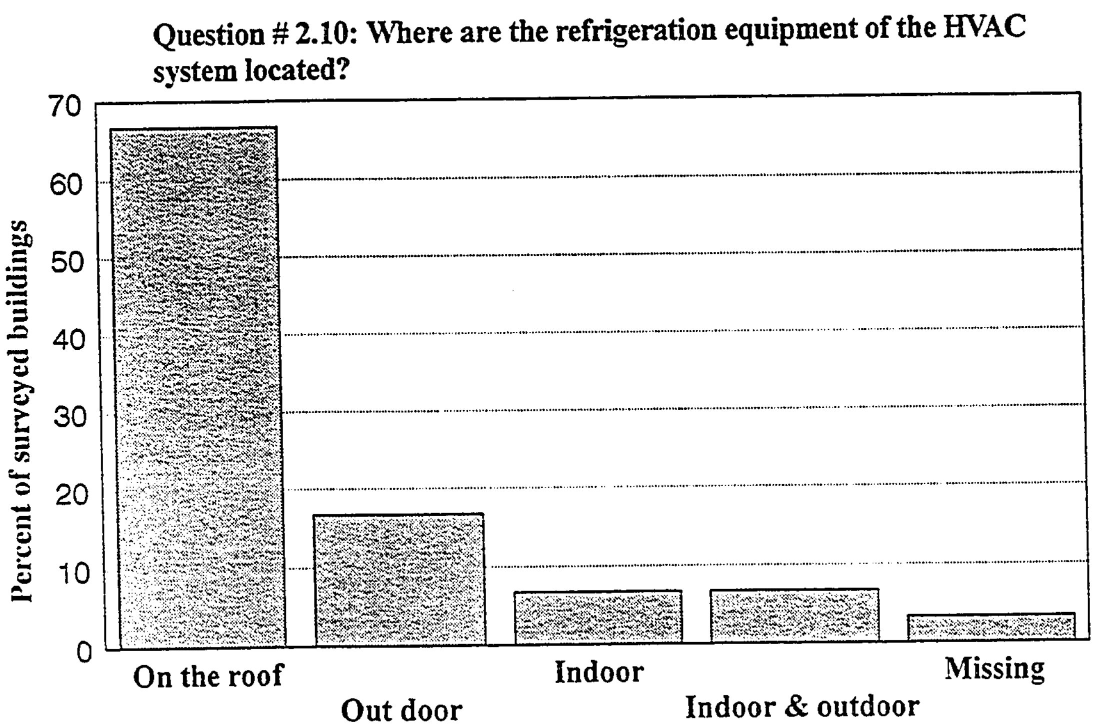


Figure 59: Refrigeration Equipment Location

Percent of Surveyed Buildings	Humidifier availability
10%	Yes
84%	No
6%	Missing

Question # 2.12 : Is the HVAC system equipped with Humidifier?

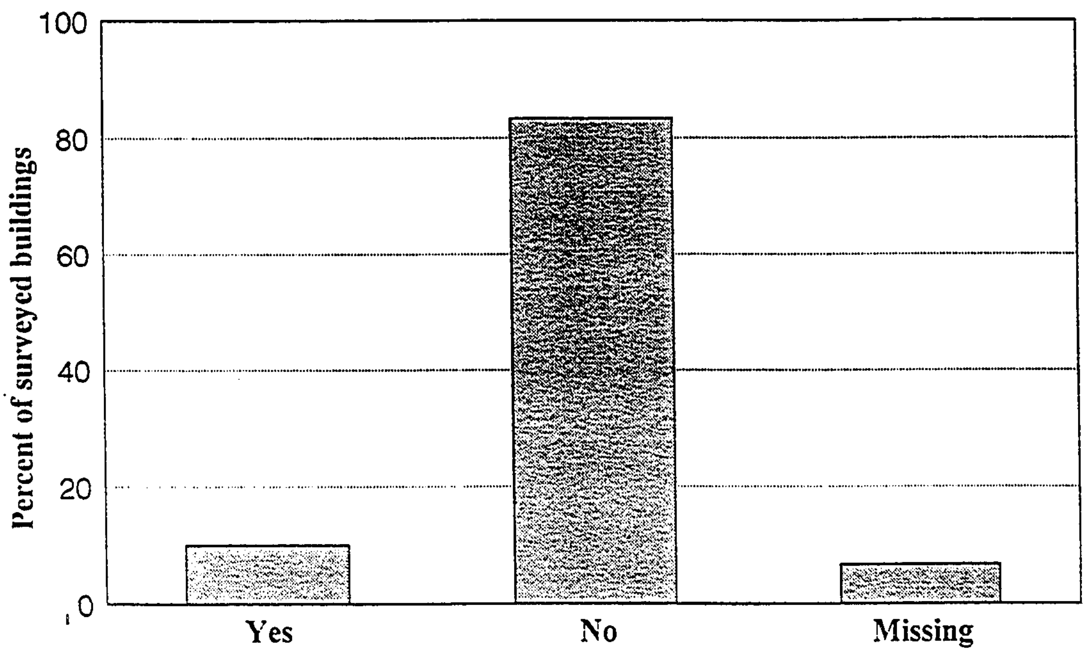


Figure 60 : Humidifier Availability

Number of Floors	Building Number
1	28
3	2,27,30,40,42
4	14,35
5	5,46,58
7	12,15,26
8	10,11,18,22,57
9	17,19,23,37,53
10	7
14	24,34
16	50

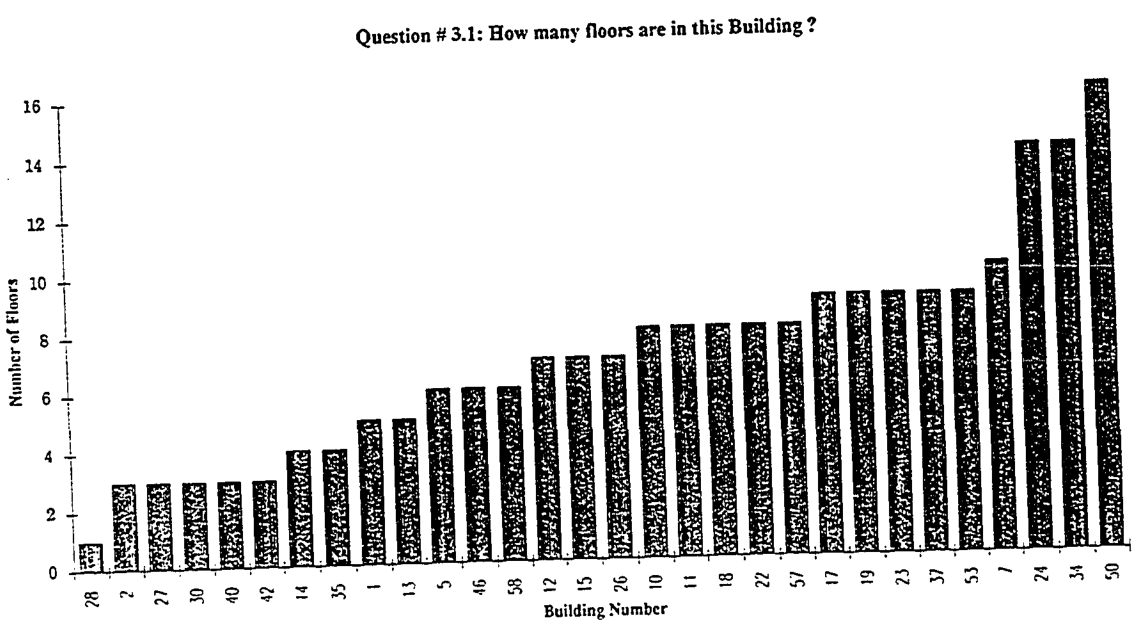


Figure 61 : Number of floors

Percent of Surveyed Buildings	Car Parking Garage
40%	Yes
60%	No

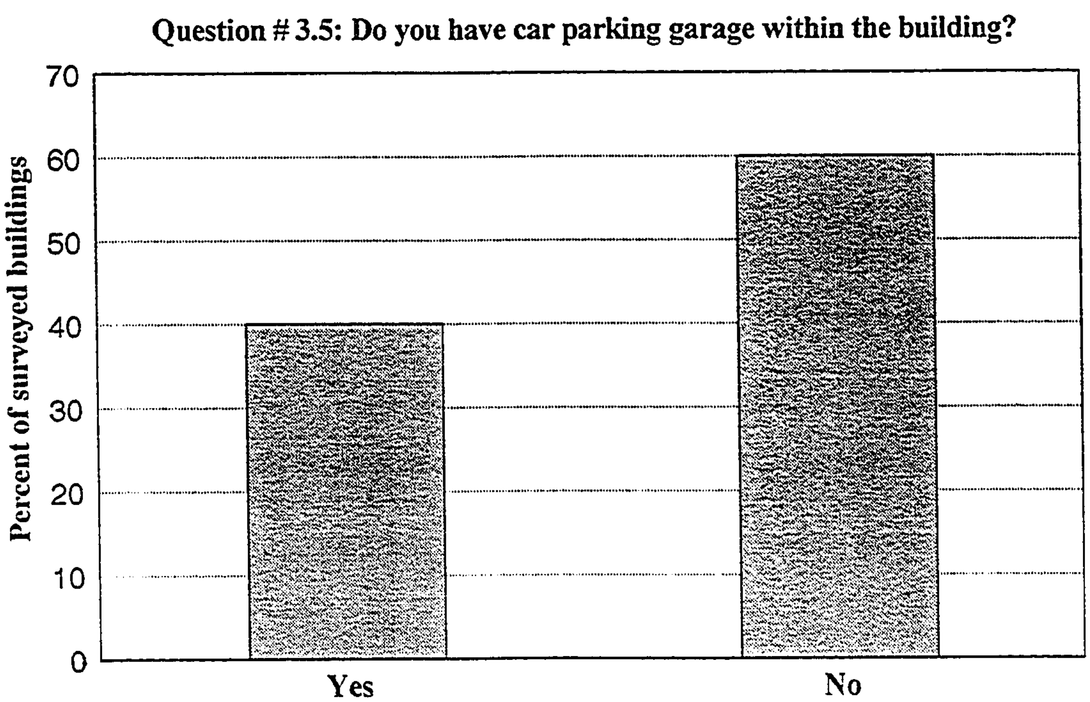


Figure 62 : Car Parking Garage

Percent of Surveyed Buildings	Loading dock
36%	Yes
60%	No
4%	Missing

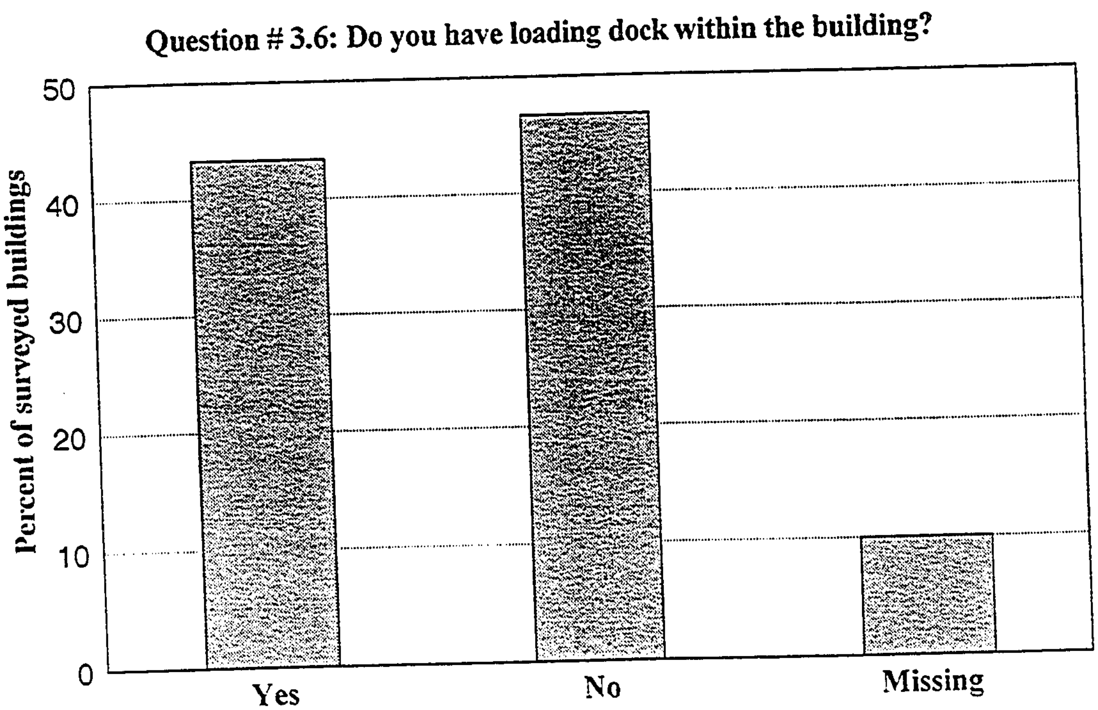


Figure 63 : Loading Dock

Percent of Surveyed Buildings	Office layout
67%	Flexible
26%	Fixed
7%	Both

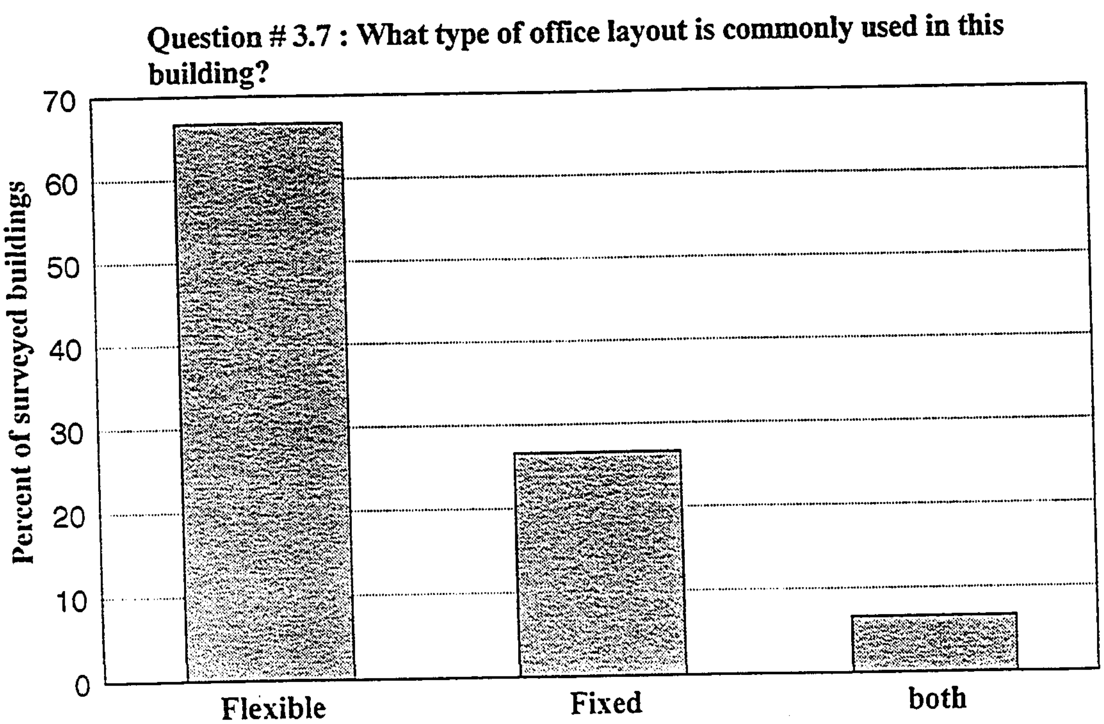


Figure 64 : Office Layout

Percent of Surveyed Buildings	Copy Machine Location
27%	Copy machine room
73%	Scattered in many locations

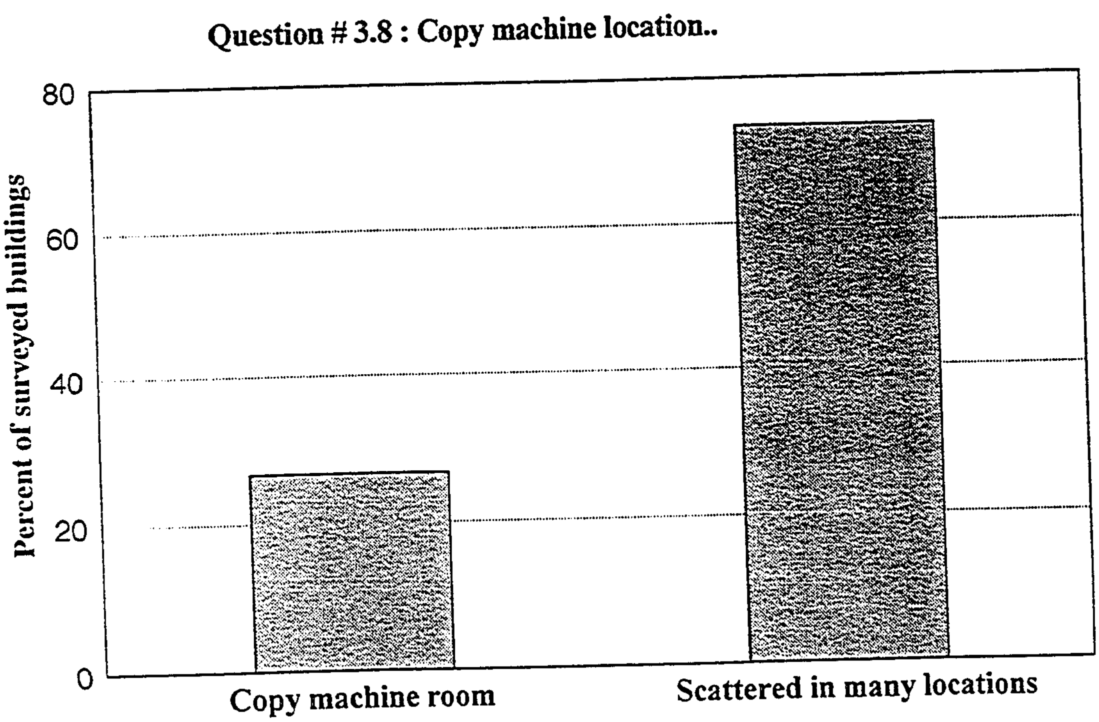


Figure 65 : Copy machine location

Percent of Surveyed Buildings	Smoking lounge
23%	Yes
77%	No

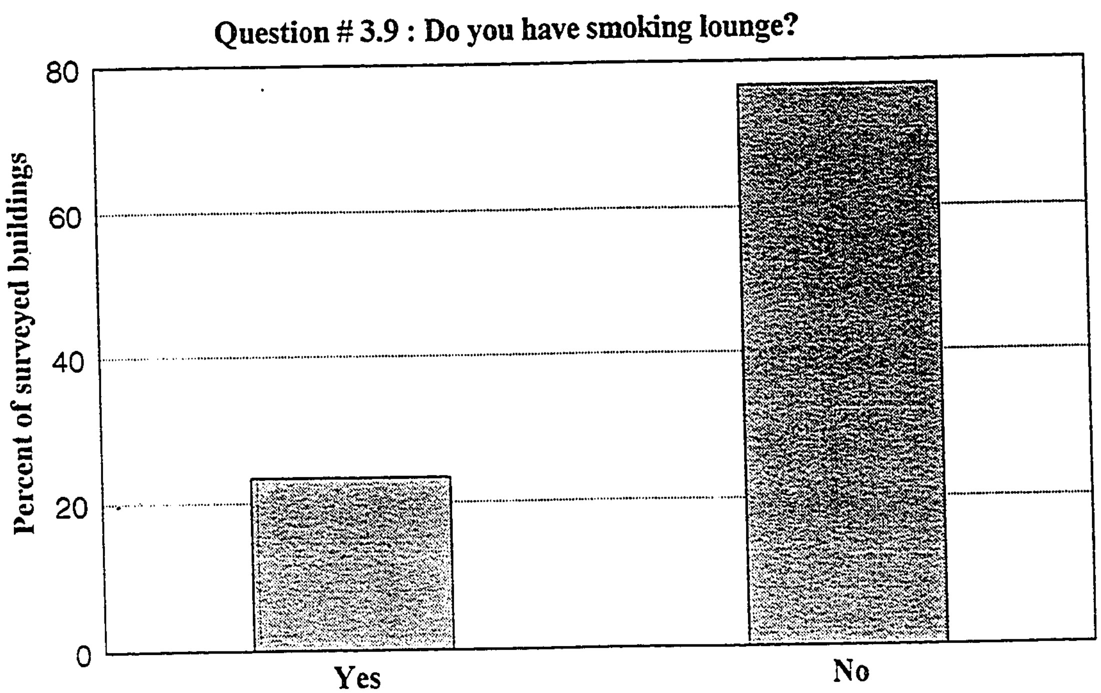


Figure 66: Smoking lounge

Percent of Surveyed Buildings	Carpet fixing method
87%	Glue
3%	Tape
3%	Mechanical Fasteners
7%	Layedout units

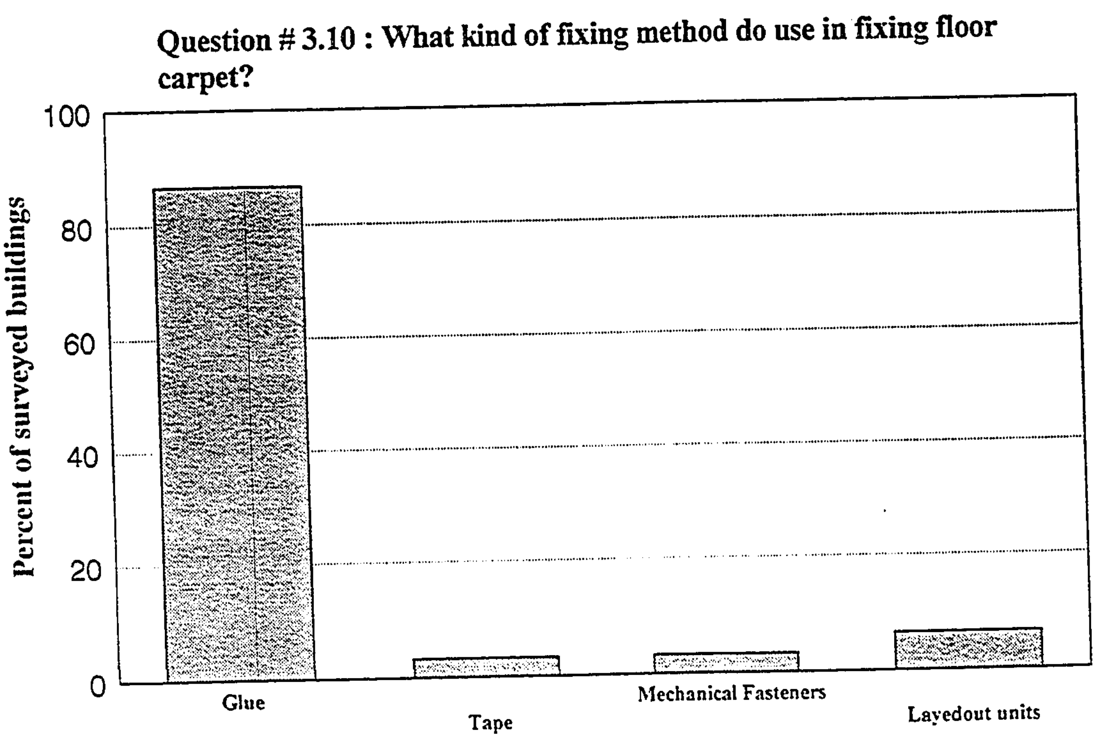


Figure 67: Carpet fixing method

Percent of Wall Paper	Building number
0%	1,7,....58
10%	2,5,24,34,35,42
20%	40
40%	22
50%	50
70%	18
100%	10

Question # 3.11: What is the percentage of wall paper on the interior walls of the buildings?

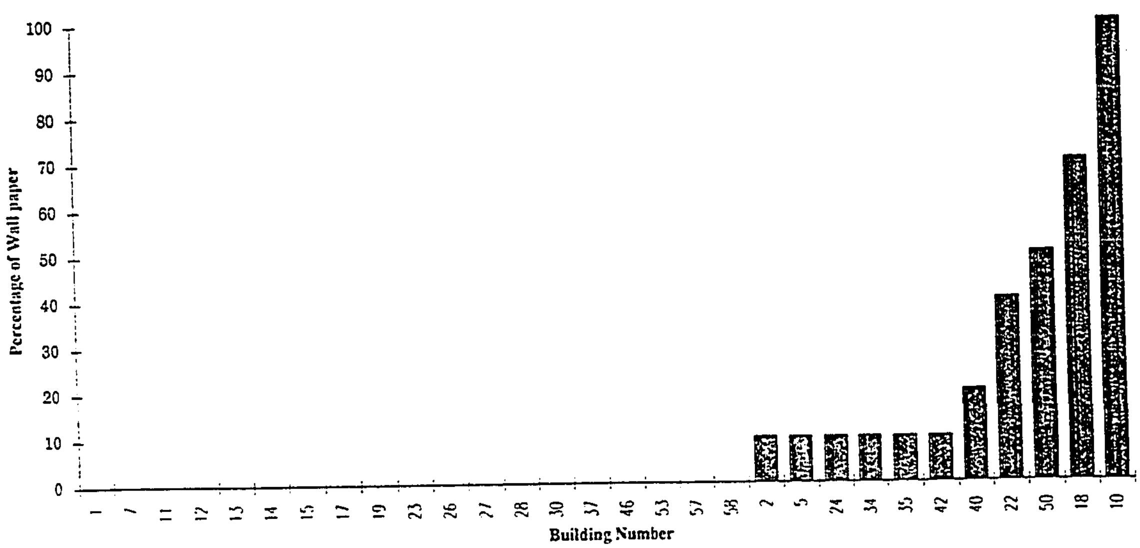


Figure 68 : Wall paper Percentage

Percentage of wood paneling	Building Number
0%	2,10,11,...53
10%	5,7,12,15,22,24,27,34,35,42
30%	1,13,58
40%	28,40
70%	30
90%	57
100%	46

Question # 3.12: What is the percentage of wood paneling on the interior walls of this building?

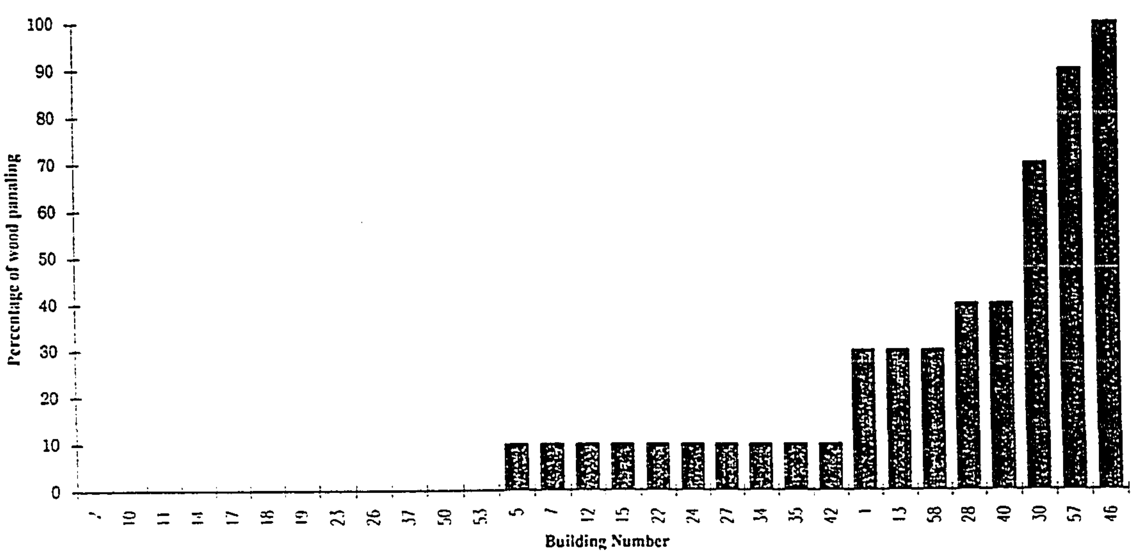


Figure 69 : Wood Paneling

Percentage of carpeted floor	Building Number
30%	22
50%	28
70%	12,15,18,30
80%	1,13,26,58
90%	2,5,7,10,11,27,57
100%	14,17,19,.....53

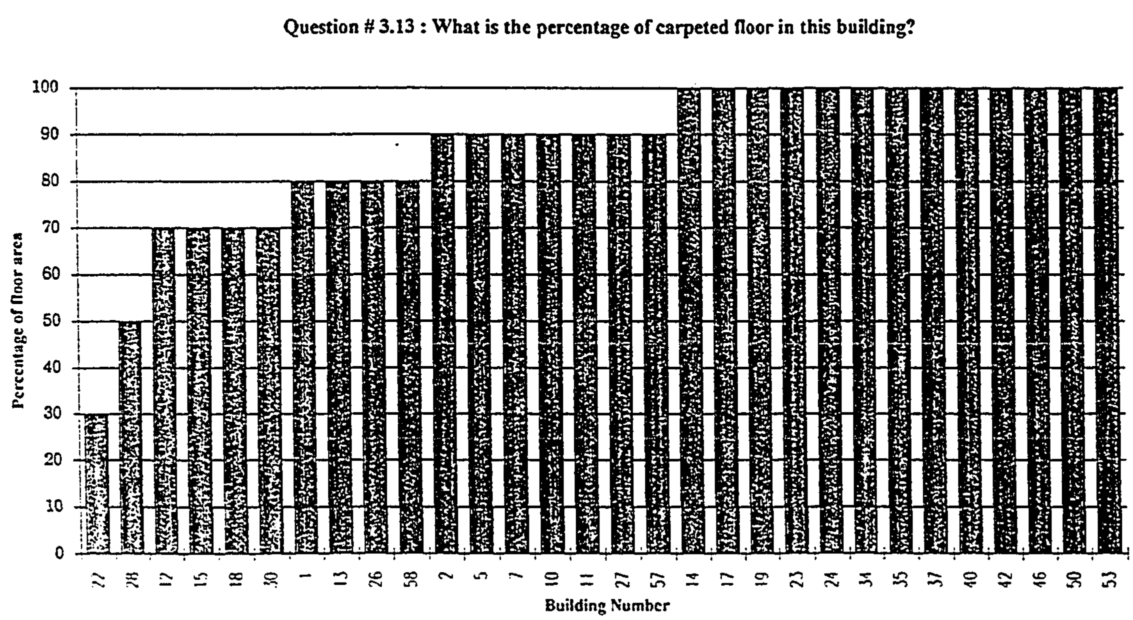


Figure 70 : Carpeted floor Area

Percent of surveyed Buildings	Building Envelop
46%	Concrete
19%	Curtain wall
5%	Cmu with internal insulation
30%	Glass

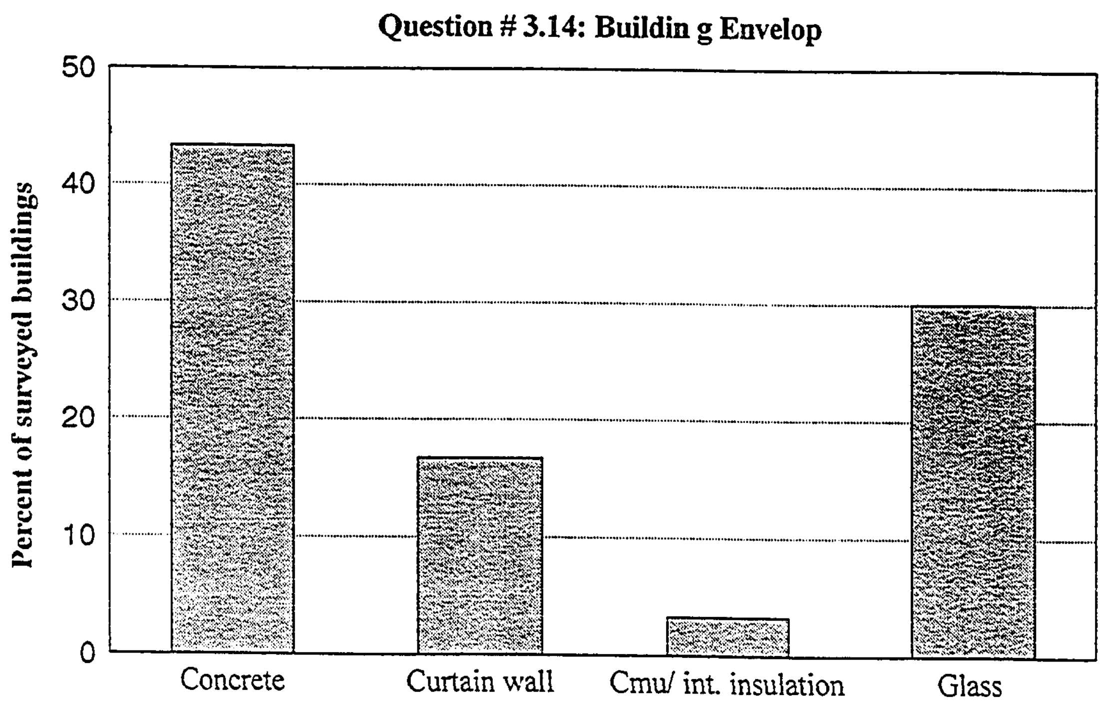


Figure 71 : Building Envelop

Percent of surveyed Buildings	Furniture Material
26%	Hardwood
10%	Particle board
40%	Metal
10%	Fiberglass
7%	Mixed
7%	Missing

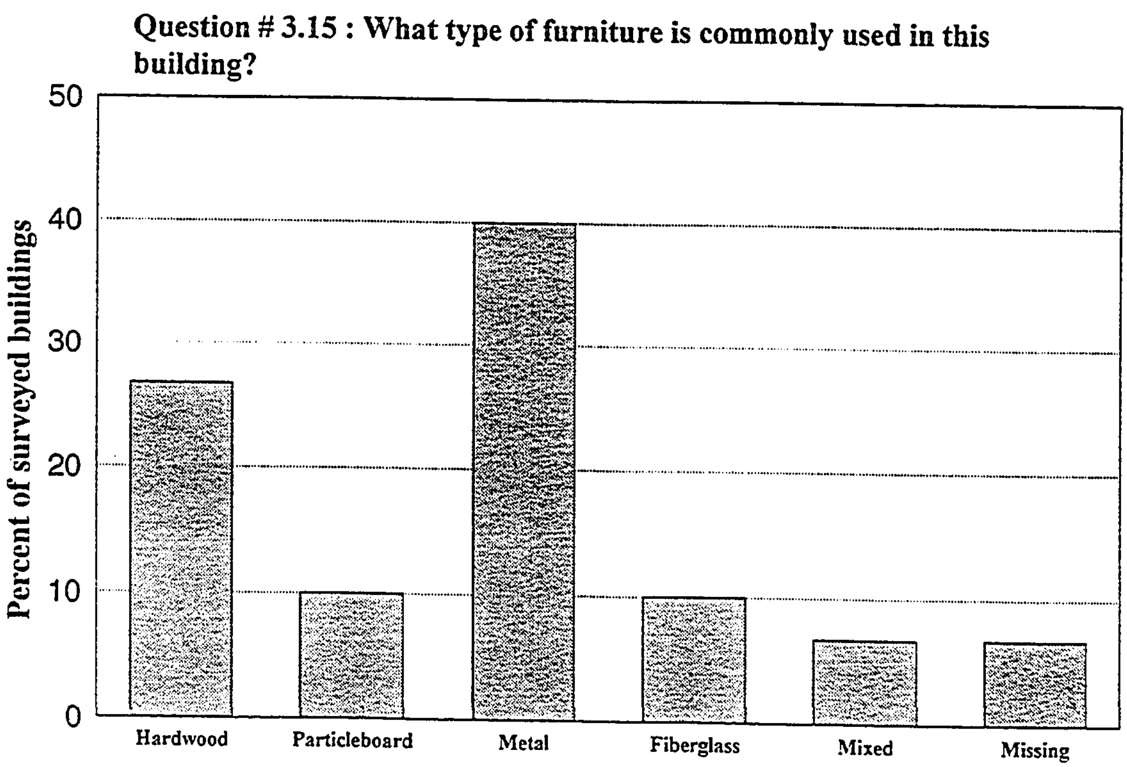


Figure 72 : Furniture Material

4.2.5 Data Analysis

Throughout the remaining of this chapter the, the results of the two surveys are going to be analyzed within the context of the research objectives. The purpose of this analysis is to achieve the remaining objectives of the research, which are:

1- to investigate the relation between the reported symptoms and the other categories of the occupants questionnaires.

2- to nvestigate the existence of sick buildings among the surveyed buildings.

3- to determine why some buildings are sick and some others are not, by investigating the relation between the occupant survey questions and the buildings system information collected in the building survey.

4.2.5.1 Occupants' Questionnaire Analysis

The collected occupant questionnaires (846 questionnaires from all the buildings), have been input into a statistical program called SPSS (Statistical Package for Social Science). The questionnaires were entered into the program as cases (846 cases) and the answers for the questions as variables (41 variables). Figure 73 illustrates this arrangement. The provided answers for each question were given a number, in order to perform the required statistical analysis. The assigned number for each answer is presented in Table 18.

		Question #1	Question # 2	Question # 3	....	Variables
Cases	Questionnaire #1	1	5	2		
	Questionnaire #2	3	1	1		
	Questionnaire #3	5	2	1		
	..					
	..					

Figure 73 : Arrangement of Occupants' Questionnaire Input

Table 18 : Occupant's questionnaire answers & assigned values

Qust. #	Question	Answers	Assigned value
1	Age	20 - 30	1
		30 - 40	2
		40 -50	3
		50- 60	4
		Over 60	5
2	Occupation	low rank	1
		middle rank	2
		manager	3
		Executive	4
3	Nationality	Saudi	1
		Arab	2
		Asian	3
		European	4
		American	5
4	Illness	Yes	1
		No	2
5	Medication	Yes	1
		No	2
6	Working period	one month or less	1
		2-6 months	2
		6-12 moths	3
		over a year	4
7	Working hours	one hour or less	1
		2-4 hours	2
		4-6 hours	3
		6-8 hours	4
8	Productivity	Same as before	1
		Better	2
		Worst	3
9	Smoking	Yes	1
		No	2
10	Feeling relived	Yes	1
		No	2
11	Room temperature	Cold	1
		Cool	2
		Slightly cool	3
		Neutral	4
		Slightly warm	5
		Warm	6
		Hot	7
		Fluctuating	8

Continue...Table 18

Qust. #	Question	Answers	Assigned value
12	Air Humidity	Very dry	1
		Dry	2
		Normal	3
		Humid	4
		Very humid	5
13	Air clarity	Clear	1
		Dusty	2
		Smoky	3
14	Air movement	Still air	1
		Little movement	2
		Drafty	3
15	Air sensation	Face	1
		Back of the neck	2
		Hands	3
		Feet	4
		All over	5
16	Odor	No odor	1
		Slight odor	2
		Moderate odor	3
		Strong odor	4
		Very strong odor	5
		Over powering	6
17	Odor Sources	Body odor	1
		Toilet	2
		Food smells	3
		Cigarette smells	4
		Car exhaust	5
		Furniture smells	6
		Dust smells	7
		Combination	8
18	Windows availability	Yes	1
		No	2
19	Windows orientation	North	1
		East	2
		South	3
		West	4
		Northeast	5
		Northwest	6
		Southeast	7
		Southwest	8
		Corner	9

Continue...Table 18

Qust. #	Question	Answers	Assigned value
20	Windows opining	Yes No	1 2
21	Windows opining frequency	Never Seldom Sometimes Often	1 2 3 4
22	Noise level	Very quite Moderate Noisy Very Noisy	1 2 3 4
23	Lighting level	Low Satisfactory Intense	1 2 3
24	Dust accumulation	Very little Little Moderate Too much	1 2 3 4
25	Symptoms	Never Seldom Sometimes Often	1 2 3 4
26	Reduction in productivity	Never Seldom Sometimes Often	1 2 3 4
27	Absenteeism	Never Seldom Sometimes Often	1 2 3 4
28	Final opinion	Comfortable Comfortable / need changes Not comfortable	1 2 3

4.2.5.2 Statistical Analysis Tools:

Among the many available statistical analysis tools, ***correlation*** was found to be the best tool to measure the relation between two variables. The Reported Symptoms Index for each questionnaire is analyzed by statistical correlation. The correlation formula used her is:

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y^2)]}} \quad \text{(Korin,1977)}$$

Where r = the coefficient of correlation

n= number of cases (filled in questionnaires)

X = Variable   Y = Variable

The correlation coefficient ranges from -1 to +1 . The closer the value to 1 the stronger the association between the tested variables. The closer the value to 0 the weaker the association. The negative sign represents the direction of association. Also, correlation coefficients can be compared among them selves to find which is stronger. The correlation calculation was made between RSI and the other variables (Questions) in the occupants' questionnaire, in order to investigate the effect of these variables on the RSI. The calculated correlation coefficients are presented in Appendix C. Table 19 list the results of the correlation analysis. Also this result is presented graphycally in Figure 74. The following could be concluded from the table and the figure:

1- The reported symptoms by the occupants has a very strong positive association with reduction in occupants' productivity and absenteeism. This is the result of the high correlation coefficients between the RSI and the " Reduce work" and " Leavwork" variables in the chart in the "Others" category. Also, respondents with high RSI tend to answer "No": they don't feel relived when leaving the building. This is clear from the negative sign for the correlation coefficient for this question (See Table 17 for assigned values). The air speed and movement (Airmov and Airsens) around the body have small coefficients; therefore their effect on the RSI is minimal.

Table 19 : Correlation coefficients for RSI vs. occupants' Questionnaire variables

Catagory	Variable	Abbreviation	Correlation Coefficient
IAQ	Odor Strength	Odor	0.3872
	Dust accumulation	Dust	0.2966
	Air clarity	Clarity	0.2563
	Odor Source	Source	0.1957
Physical	Noise level	Noise	0.2317
	Lighting Level	Light	-0.1156
Background	Hours spent in space	Hours	0.08
	Occupant's Age	Age	-0.0771
	Long term medication	Med.	0.0733
	Months spent in space	Months	0.066
	Long term illness	Illness	0.0626
	Occupant's Nationality	Nation.	0.043
	Smoking status	Smoking	0.0251
	Occupation	Occup.	0.0121
Thermal	Room temperature	Temp.	0.0899
	Air humidity	Humid.	-0.0818
	Window orientation	winorint.	0.0485
Others	Reduction in work ability	Reducwork	0.4958
	Leaving work or absenteeism	leavwork	0.36
	Relived when leaving the building	Relived	-0.1756
	Air sensation	Airsens.	0.015
	Air movement	Airmov.	0.0054

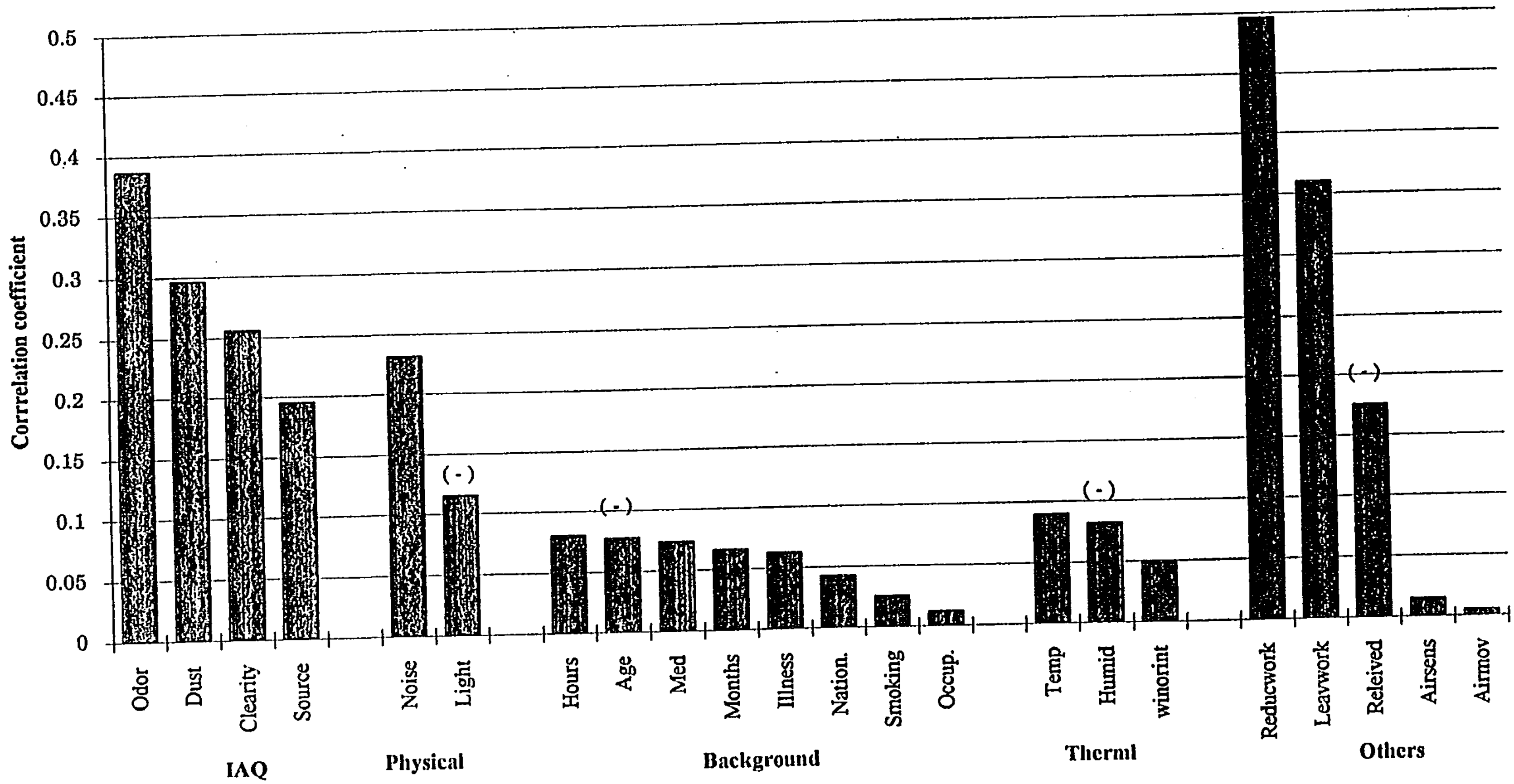


Figure 74: RSI CORRELATION WITH OCCUPANT'S QUESTIONNAIRE VARIABLES

2- The strength of odor reported by occupants has the strongest association with the reported symptoms. Based on the assigned values for the odor answer, the stronger the odor the higher the RSI. The other variables of the IAQ have positive correlation coefficients and high coefficients compared to the other groups, which indicates that the IAQ category of questions have the strongest association with the reported symptoms among the other categories which might affect the reported symptoms.

3- The next strongest is the physical category (Light and noise). The noise variable has a positive coefficient, which indicates that the higher the noise level , the higher the RSI. On the other hand, the lighting levels has the opposite effect. The negative sign of coefficient indicates an inverse relation between lighting levels and the RSI. The lower the lighting level , the higher the RSI.

4- The thermal category is the fourth lowest category. Room temperature has a positive correlation coefficient and humidity has a negative coefficient. Both of those coefficients are small in value compared to the other categories., which reflects a weaker association between the thermal category and the RSI. The negative sign of the humidity variable shows that most occupants with high RSI tend to report low humidity in the air (dry air).

5- The background variables have the lowest total coefficients, which clearly indicates the weak association of those variables with the RSI. The negative sign of the occupants age indicates that occupants reporting high RSI tends to be in the lower age groups (see table 18).

4.3.5.3 Sick buildings:

A building is diagnosed as a sick building if 20% or more of the occupants have experienced one or more of the symptoms. Based on this definition and based on the outcome of the statistical analysis above, sick buildings among the surveyed sample of buildings could be determined. As seen from Figure 34, which demonstrates the calculation method for the RSI, the RSI scale has a lowest value of 1.3 and a highest value of 5.2.

This scale represent the frequency of experiencing the selected symptom. The mid point in this scale is 3.2. Therefore, the sick buildings are decided based on the percentage of RSI values higher than the average value. If this percentage is higher than 20% then the building is sick. After analyzing the RSI for each building the percentage of occupants reporting RSI greater than 3.2 in each building was found and presented in Figure 75.

Based on the 20% criteria above the graph, shows that 9 building out of the 30 buildings have more than 20% of the occupants' RSI higher than 3.2. These buildings vary from 21% to 50% which is the heights value. Therefore, these buildings could be considered "Sick Buildings".

4.2.5.4 Buildings' Questionnaire analysis:

The percent of occupants who reported RSI higher than 3.2 varies from 0 to 50 % as indicated in figure 20 . In order to find an explanation for this, the percentage of occupants reporting RSI higher than 3.2 in each building is correlated with collected building systems information in the building survey. This percentage will be used intensively throughout the remaining section of this chapter and PO (Percent of occupants reporting RSI higher than 3.2) will be used as an abbreviation.

The answers for each question of this questionnaire were entered as numbers in order to facilitate the statistical analysis. Table 20 lists the assigned values for the Building Questionnaire answers.

The correlation calculations were made for the PO vs. the answers of the Building questionnaire. Table 21 and Figure 76 present the correlation coefficients for the categories of the building questionnaire. Each group of factors is discussed below.

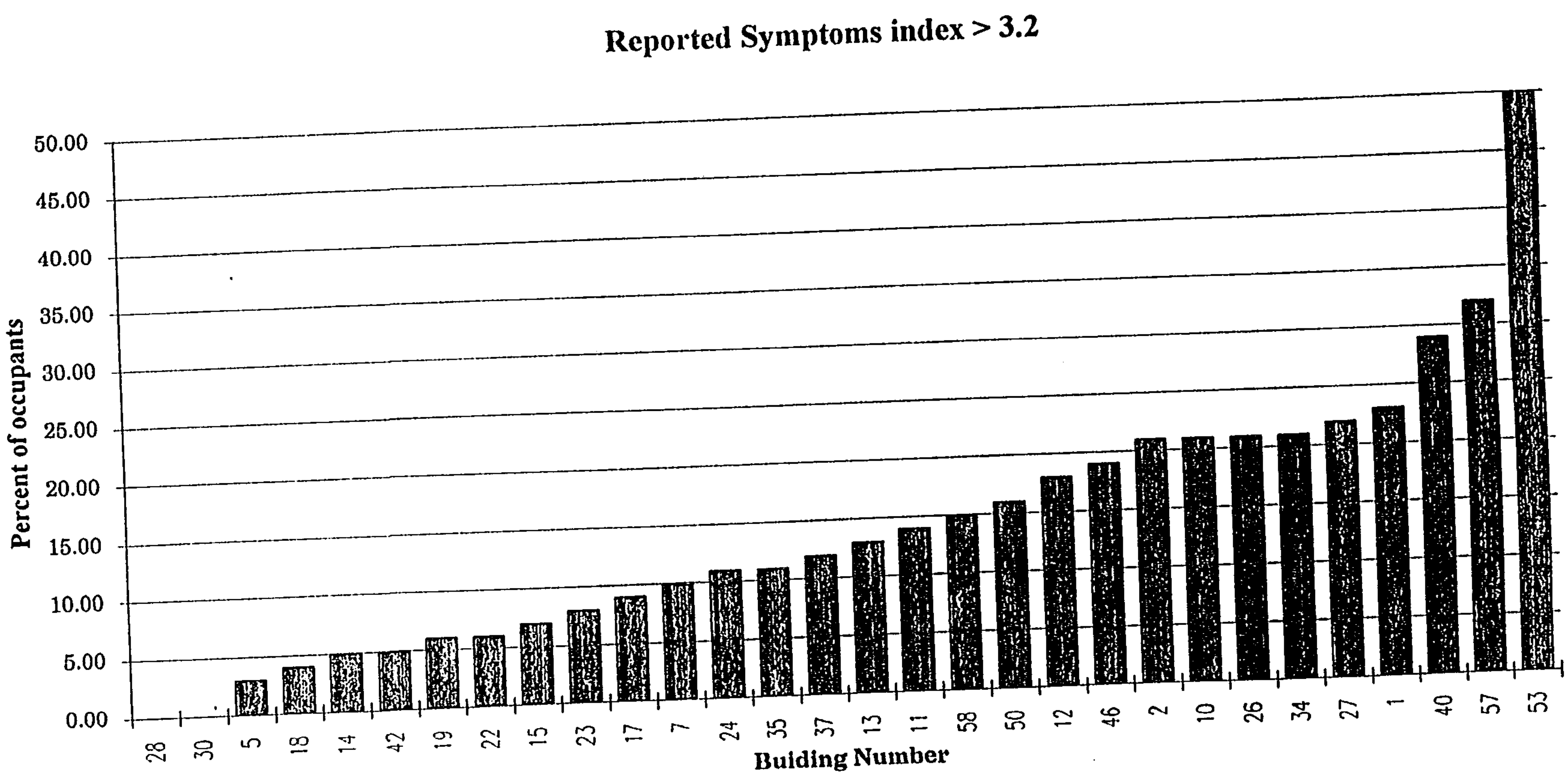


FIGURE 75 : PERCENT OF OCCUPANTS REPORTED RSI > 3.2 IN ALL BUILDINGS

Table 20 : Building's questionnaire answers & assigned values

Qust. #	Question	Answers	Assigned value
1.1	Building Age	Years	
1.2	Operation and Maintenance is performed by	Self maintenance	1
		One contractor	2
		Several contractors	3
		On call contractor	4
1.3	Building Maintenance Pattern	All corrective	1
		70% Corrective 30% PM	2
		50% Corrective 50% PM	3
		20 % Corrective 80% PM	4
1.4	Carpet shampooing	Only when needed	1
		Once a month	2
		Twice a month	3
1.5	Floor cleaning	Once a week	1
		Every other day	2
		Daily	3
1.6	Maintenance Manuals	Not available	1
		Partially available	2
		Available	3
1.7	As built drawings	Not available	1
		Partially available	2
		Available	3
1.8	Pest control use	Yes	1
		No	2
1.9	Pest control schedule	Only when needed	1
		Regular schedule	2
2.1	HVAC system	All water system	1
		Air and water system	2
		Package units	3
		All air system	4
2.2	Duct material	Galvanized steel	1
		Fiberglass	2
		Both	3
2.3	Filter type	Panel greased surface	1
		Panel dry surface	2
		Moving greased curtain	3
		Moving dry curtain	4

Continue...Table 20

Qust. #	Question	Answers	Assigned value
2.4	Economizer cycle	Yes No	1 2
2.5	Fresh air supply rates	5 cfm/ person 10 cfm/person 15 cfm/person 20 cfm/person	1 2 3 4
2.6	HVAC system testing	None once twice twice three times only after renovation	1 2 3 4 5
2.7	Duct cleaning	None Once Twice Three times	1 2 3 4
2.8	HVAC preventive maintenance	None Once a year Twice a year Three times a year Four times a year	1 2 3 4 5
2.9	HVAC system operation mode	24 hours office hours only two hours earlier	1 2 3
210	Refrigeration equipment location	On the roof outdoor indoor indoor & outdoor	1 2 3 4
2.11	Return air	By ducting By plenum	1 2
2.12	Humidifier	Yes No	1 2
3.1	Buildings number of floors	Total number of floors	floors
3.2	Office floors Commercial floors Residential floors	Office floors only Commercial floors only Residential floors only	floors floors floors
3.3	Number of offices in each floor		office

Continue...Table 20

Qust. #	Question	Answers	Assigned value
3.4	Occupants population	person	
3.5	Car parking garage	Yes No	1 2
3.6	Loading dock	Yes No	1 2
3.7	Office layout	Flexible Fixed Both	1 2 3
3.8	Copy machine location	in copy machines only scattered in many locations	1 2
3.9	Smoking lounge	Yes No	1 2
3.10	Carpet fixing method	Glue Adhesive tape Mechanical fasteners Layout	1 2 3 4
3.11	Percentage of wall paper		%
3.12	Percentage of wood panels		%
3.13	Percentage of carpeted floors		%
3.14	Building envelop	Concrete Precast concrete CMU with interior insulation Cmu with exterior insulation Sandwich cmu wall Curtain wall Glass	1 2 3 4 5 6 7
3.15	Furniture	Hard wood Particle wood Metal Fiberglass Mixed	1 2 3 4 5
4.1	Indoor environment complaints	Never Seldom Sometimes Often	1 2 3 4
4.2	Health related complaints	Yes No	1 2

Table 21 : Correlation coeffecints for PO vs. Building's Questionnaire variables

Catagory	Variable	Abbreviation	Correlation Coefficient
O&M	O&M contractor	O&M	0.254
	Floor cleaning	Floorclean	- 0.25
	Pest control	Pestcont.	0.218
	As built Drawing	drawing	0.171
	Building Age	bldage	0.1604
	O&M manuals	manuals	0.09
	Maintenance Pattern	maintpatt.	-0.0505
	Carpet cleaning	carptclean	- 0.044
HVAC system	HVAC system type	hvacsys	0.4568
	HVAC preventive maintenance	hvacpm	0.2933
	HVAC system operation mod	opermod	-0.1827
	Refrigeration equipment location	refequp.	- 0.1746
	HVAC testing	testing	0.1496
	Duct cleaning	ductclean	0.1129
	Ducting material	ductmat.	- 0.0656
	Economizer cycle	econcycle	0.0604
	Humidifier	humdfr	- 0.0419
Architectural	Filter type	filter	0.0171
	Return air	retair	0.0086
	Building Envelop	envelop	0.5464
	Furniture material	furniture	0.2986
	Copy machine location	copymachn	0.1954
	Parking garage	garage	0.1809
	Smoking lounge	lounge	- 0.1749
	Number of floors	floors	0.1396
	Wood paneling	woodpanl	0.1192
	Office layout	offlay	0.0858
	Carpet Area	carptarea	- 0.044
	loading dock	dock	- 0.0396
	wall paper	wallpaper	0.0242
	Carpet fixing method	carpetfix	0.0219

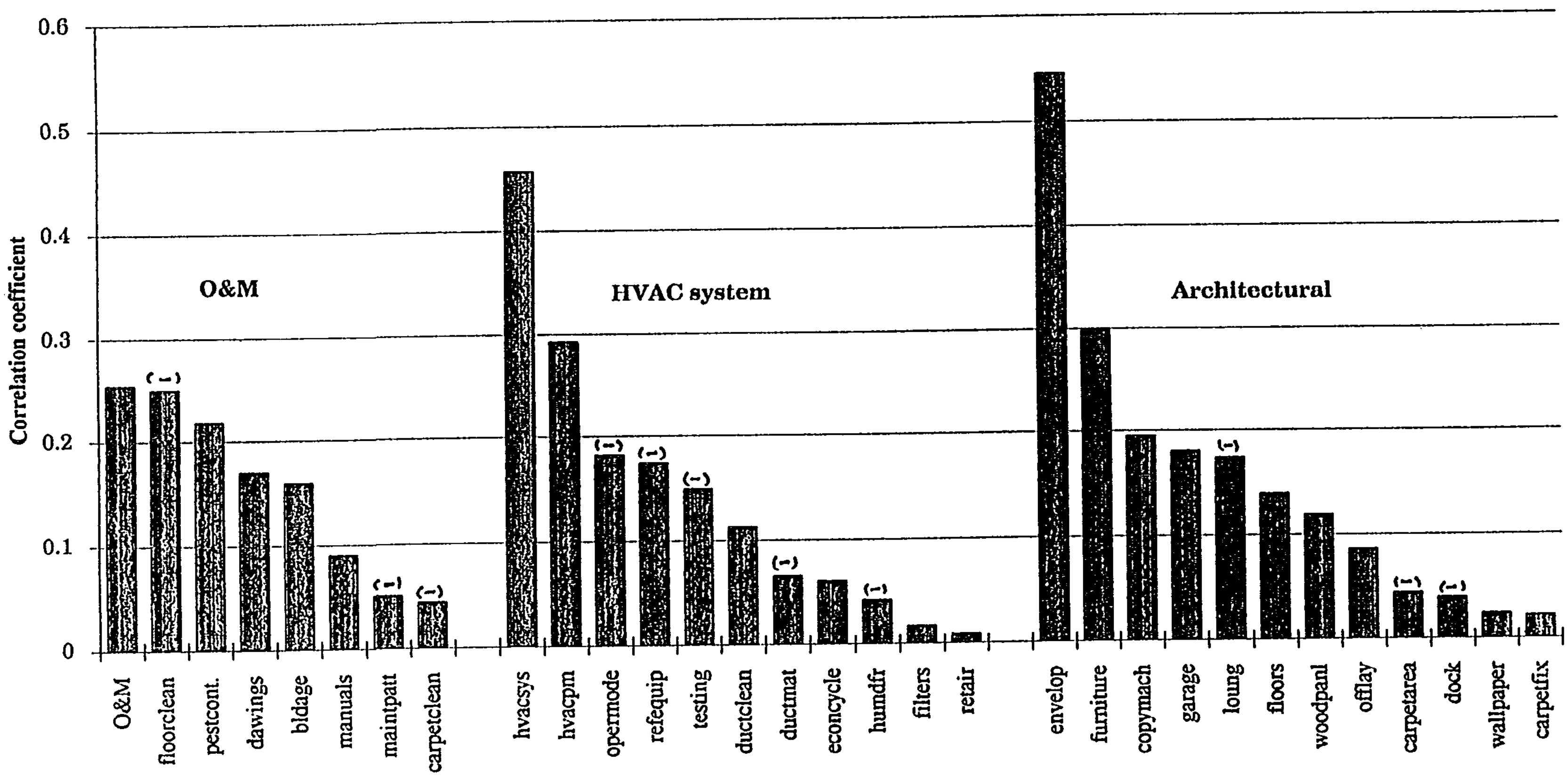


FIGURE 76 : PO CORRELATION WITH BUILDING'S QUESTIONNAIRE VARIABLES

__Operation and maintenance__: Figure 46 indicates the highest correlation between the PO (percentage of occupants reporting RSI value higher than 3.2) and question # 1.2 about who is performing the operation and maintenance. This means that buildings with a higher occupants percentage tend to have higher values of this questions's answers. From the values assigned to this question's answers, the highest values for those answers are 3 and 4, representing the answers of : specialized contractors, and on- call contractor. From this it can be concluded that sick buildings tend to be operated by several specialized contractors and the on- call contractors. The first one has the highest percentage 13.3% of all the buildings and the other has 6.7% of the buildings.

The second highest coefficient is for the floor cleaning . The negative sign of this factor indicates that higher the PO the lower the frequency of floor cleaning. This could also means that the higher the frequency of floor cleaning the lower the tendency of the building to be sick.

The third highest coefficient is for the pest control. This indicates that buildings with high PO tend to have no pest control.

As built drawing availability is shown to have a high association with PO than the operation and maintenance manuals. This could prove that sick buildings tends to have no as built drawing and that the O&M manuals are more available.

The lowest correlation coefficients are for carpet cleaning and for maintenance pattern. This reflects the importance of these factors among the others. The negative sign for both of these factors indicates negative correlation. This means the higher the PO the lower the factors which is logical considering the assigned values for the answers to those question.

__HVAC system category__: The highest coefficient in this category is the HVAC system type. This means that buildings with high PO tend to have HVAC systems with higher assigned values. The "All air system" has the highest assign value (4), therefore sick buildings, tend to have all air systems.

Due to the strong association of this factor compared to other factors, a closer look to the details of the air systems working in buildings which are above the 20% PO threshold (sick buildings) is necessary in order to look for an answer for this result.

Upon the site visits to these buildings, a schematic diagram for the air handling system was produced. The air handling systems found in these buildings are presented in Figure 77. After analyzing these systems the following could be concluded:

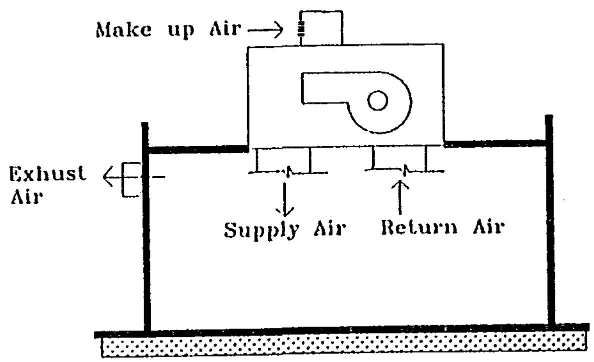
1- The Outdoor air input of systems 1, 2, and 3 relies on the exhaust system. By exhausting the indoor air a negative pressure is created. In case of the system is equipped with relief damper, (as in system #1), the outdoor air will enter the building through it. If there is no relief damper or the relief damper is clogged or malfunctioning, the outdoor air will enter the building through the building envelop which is the worst case because the outdoor air will be hot and unfettered. Also the introduced fresh air will not properly mix with the indoor air.

2- System # 3 uses the corridor and circulation spaces as a return air plenum. These are usually heavily populated areas and smokers tends to smoke in those areas.

3- System # 4 is an ideal system with respect to IAQ, because it has a separate air handling system for filtration , cooling, dehumidifying and distributing the outdoor air. Building # 53 has the highest PO even though it has this system.

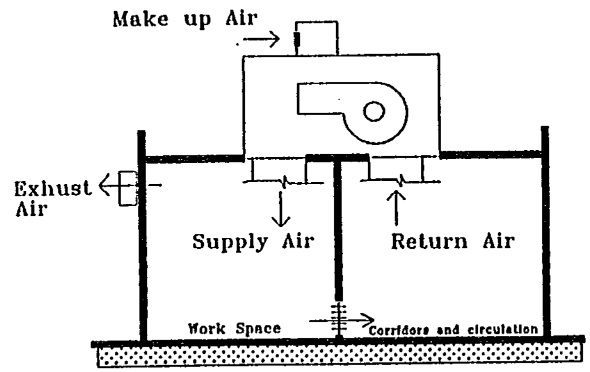
The second highest coefficient is the HVAC preventive maintenance frequency. It indicates that the higher the PM rate for HVAC system the higher the PO. This result is giants the logical relation between IAQ and preventive maintenance. This proof nothing but, the invalidity of information collected for this factor factor.

The operation mode factor is the next highest factor. The coefficient is negative, which means the higher the PO, the lower the assigned value. This means that buildings with high PO tends to have the HVAC in operation 24 hr.



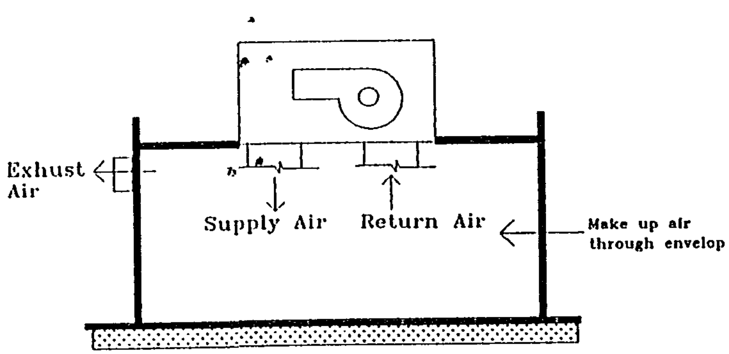
Air Handling System # 1

Building # 34
Building # 26



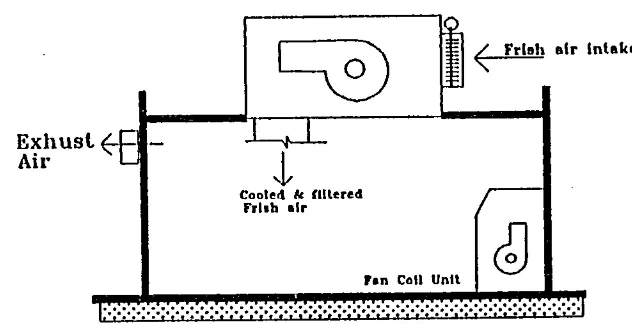
Air Handiling System # 3

Building # 57
Building # 40
Building # 1
Building # 27



Air Handling system # 2

Building # 10 and # 2



Air Handling System # 4

Building # 53

FIGURE 77 : COMMON AIR HANDLING SYSTEM IN SICK BUILDINGS

The next highest factor is the refrigeration equipment location. The negative value of this coefficient indicates that buildings with high PO tend to have the refrigeration equipment on the roof (the lowest assigned value = 1).

Testing is the next with a negative sign. This also means the building with high PO has low frequency of testing and balancing the HVAC system. The same is true for duct cleaning factor.The other factors have low coefficients, therefore low association with PO compared to the other factors.

Architectural Category: The highest coefficient in this category is the coefficient for the building envelop. This is the highest coefficient in all the categories. It represents the strongest association with the PO. The higher the PO, the higher the assigned value for the building envelop, which means that buildings with high PO tend to have glass envelop (the highest value). Due to that, 6 buildings at the top of the PO chart have glass envelopes.

The next highest is the type of furniture coefficient. This factor is the second highest in this category and in all other categories, which reflects the importance of the type of furniture to the PO compared to other factors. Mixed furnture have the highest assigned values (5). This indicates that buildings with hegh PO tends to have "Mixed furnture".

Copy machine location has the third position in this category. The lower assigned value for this question is 1 representing " only in copy machine room" and the highest value is 2 representing " scattered in many locations). This means that buildings with high PO tends to have copy machines scattered in many locations. The availability of a garage in the building is next. Analyzing the chart with the assigned values. It shows that buildings with high PO chart tend to have no garages within the building.

The smoking long factor is negatively high because most buildings with high PO have no smoking lounge. The next factor to consider is the number of floors, the positive coefficient indicates that buildings with high PO tend to have higher number of floors than buildings with low PO.The other factors in this category have considerably low coefficients that other factors, which reflects the week association between them and the PO.

CHAPTER 5 : CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

1- The IAQ factors Have the highest effect on the reported symptoms with the following correlation factors:

1- Odor Strength	0.3872
2- Dust accumulation	0.2966
3- Air clarity	0.2563

2- The Physical factors have the second highest effect on the reported symptoms with the following correlation factors:

1- Noise	0.2317
2- Light	-0.1156

3- Sick Building syndrome symptoms cause a decrease in productivity and an increase in absenteeism rate. 74% of the occupants who experienced a high rate of the symptoms reported a reduction in productivity. Whereas only 25% of the occupants with low rate of the symptoms reported a reduction in productivity

4- 30% of the surveyed buildings are proven to be "Sick Buildings"

5- 67% of the sick buildings have glass envelop

6- 44% of the sick buildings have "All Air" HVAC system

7- 44% of the sick buildings use corridors as a return air plenum

8- 33% of the sick buildings have a percentage of synthetic resin furniture.

9- Internal duct cleaning and HVAC system testing and balancing are not part of the preventive maintenance tasks in the surveyed buildings

10- The role of municipal authorities in controlling the indoor environment in buildings is missing.

5.2 Recommendations

Listed below are recommendations for preventing IAQ problems in office buildings:

5.2.1 Design Recommendations:

1- Exterior glass envelopes should be avoided due to their negative effect on increasing the thermal loads of the buildings plus it's negative role on IAQ.

2- Smoking lounges should be included in the building design. This will isolate the smoking effect in one area which can be controlled by the HVAC system.

3- In the design of the HVAC system the use of an air plenum should be avoided

4- Fresh air intake should be distributed among all building spaces.

5- Air handling systems should be provided with high efficiency filters and more than one type of filter medium.

6- An economizer cycle should be provided to control the amount of outdoor air and reduce energy consumption.

7- Fiberglass ducting should be not be used at all in the HVAC system

8- Cooling coils should not be located in the occupied zone

5.2.2 Operation and Maintenance Recommendations:

1- Preventive maintenance for all building's systems should be applied very strictly, especially the cleaning of all filters and drainage pans in the air handling units.

2- Daily cleaning of uncarpeted floors is recommended

3- Carpet shampooing should be kept to a minimum.

4- Internal duct cleaning should be performed as least on a yearly basis

5- Testing and balancing the HVAC system should occur at least every two years.

Finally, it is recommended that the municipal authorities should step in and control the indoor environment design criteria. By setting minimum requirements for HVAC design such as fresh air rate, and minimum filtration requirements . Building designs that do not fulfill these requirements should be rejected.

5.3 Possible future research:

This research investigated the IAQ problems by subjective methods, which is important in determining the big picture of the IAQ problems. However, quantitative means of investigating IAQ are very important because they relays on measurement of indoor environment variables rather than depending on human judgment. Therefore, it is recommended here that a quantity IAQ research should be performed as a natural continuation of this research. It is recommended that the quantitative research should start by analyzing the buildings which are reported to be sick in this research.

APPENDIX A: LIST OF OFFICE BUILDINGS

BLDG. #	Building Name	Location	Remarks
1	Rural and Municipal Affairs building	Dammam	
2	Civil Service berue building	Dammam	
3	Jafaly office building	Dammam	
4	Alhoshan office building	Dammam	
5	Aljomih office building	Dammam	
6	Al- Turky office building	Dammam	
7	Post office headquarter	Dammam	
8	Saudi Telephone headquarter	Dammam	
9	Chamber of commerce old office buildin	Dammam	
10	GOSE building #1	Dammam	
11	GOSE building #2	Dammam	
12	Al-Mujel office buildings	Dammam	
13	Dammam municipality new office buildin	Dammam	
14	KAMO office building	Dammam	
15	AL-Mujel headquarter	Dammam	
16	Al- Gazawi office building	Dammam	
17	Al- Mulihe office Building	Dammam	
18	Al- Fadil office building	Dammam	
19	Al- Aqariah office building	Dammam	
20	Kanoo office building	Dammam	
21	SAMA office building	Dammam	
22	Al-Tamimi office building	Dammam industrial area 1	
23	SABIC office building	Dammam industrial area 1	
24	SAMARK office building	Dammam -Khobar road	
25	Zamil steel office building	Dammam industrial area 1	
26	Chamber of commerce headquarter	Dammam -Khobar road	
27	SECECO headquarter	Dammam -Khobar road	
28	CARRIER office building	Dammam -Khobar road	
29	National Guard headquarter	Dammam -Khobar road	
30	Delam office building	Dammam -Khobar road	
31	Al- Nagi office building	Dammam -Khobar road	
32	Aba-Hussin office building	Dammam -Khobar road	
33	SNAS office building	Dammam -Khobar road	
34	Floar office building	Dammam -Khobar road	
35	Al-Olian office building	Dammam -Khobar road	
36	Silver Tower office building	Khobar	
37	Zamil O&M office building	Khobar	
38	Airlines Center office building	Khobar	
39	Oasis office building	Khobar	
40	Pan Am office building	Khobar	
41	SUCO office building	Khobar	
42	SSOC office building	Khobar	
43	SACAT office building	Khobar	
44	Al-khodary office building	Khobar	
45	Cathe Basify office building	Khobar	
46	SAKHR office building	Khobar	
47	Red brick facade office building	Khobar	
48	Kingston office building	Khobar	
49	Al majal service master	Khobar	
50	Al_Kashojee office building	Khobar	
51	Ben-Zager office building	Khobar	
52	Al-Kobar municipality	Khobar	
53	Gulf center	Khobar	
54	Al hashem office building	Khobar	
55	Jadawel office building	Khobar	
56	KFUPM admin. building	Dahahran	

Appendix B : Research Questionnaires

Occupant's Questionnaire (Arabic)

بسم الله الرحمن الرحيم

وزارة التعليم العالي
جامعة الملك فهد للبترول والمعادن
كلية تصاميم البيئة
برنامج الهندسة المعمارية

Ministry of Higher Education
King Fahd University of Petroleum & Minerals
College of Environmental Design
Architectural Engineering Program

الموضوع : دراسة حول جودة الهواء الداخلي في المباني (رسالة ماجستير) .

عزيزي / مستخدم المكتب

السلام عليكم ورحمة الله وبركاته

يقوم قسم الهندسه المعماريه بجامعة الملك فهد للبترول والمعادن بأجراء دراسه حول جودة الهواء في البيئه الداخليه للمباني المكتبيه وذلك من خلال رساله ماجستير. وتهدف هذه الدراسه الي تقييم جودة الهواء في البيئه الداخليه استنادا الي تقييم المستخدمين للهواء والبيئه الداخليه من حولهم وكذلك تقييم انظمة المباني .

ولهذا نود ان تساعدنا بصفتك احد المستخدمين لمكاتب في هذه الدراسه بتعبئة الأستفتاء المرفق. والمعلومات التي ستقوم بتقديمها في هذا الأستفتاء على جانب كبير من الأهميه بالنسبه للدراسه ونقدر لك الجهد والوقت الذي ستقضيه في تعبئة هذا الأستفتاء. كما نود ان نخبرك بأن جميع المعلومات التي ستدرجها في هذا الأستفتاء سوف تحفظ في سريه تامه وتستخدم لأغراض البحث العلمي .

نشكرك مقدما على المساعده ونأمل تعبئة الأستفتاء باللغه العربيه او الأنجليزيه ايهما افضل بالنسبة لك وعند الحاجه لمعلومات اضافيه او استفسارات يمكن الأتصال بالطالب علي سعيد القحطاني على الرقم ٨٤٢٩٥٤٥ او الدكتور عبدالمحسن الحماد على الرقم ٨٦٠٣٥٨١ .

والسلام عليكم ورحمة الله وبركاته

١٥/٦/٩٧

الدكتور / عبدالمحسن الحماد . استاذ مشارك

علي سعيد القحطاني . طالب دراسات عليا

بسم الله الرحمن الرحيم

Ministry of Higher Education
King Fahd University of Petroleum & Minerals
College of Environmental Design
Architectural Engineering Program

وزارة التعليم العالي
جامعة الملك فهد للبترول والمعادن
كلية تصاميم البيئة
برنامج الهندسة المعمارية

الموضوع : دراسة حول جودة الهواء الداخلي في المباني (رسالة ماجستير)

عزيزي / مستخدم المكتب

السلام عليكم ورحمة الله وبركاته

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والسلام عليكم ورحمة الله وبركاته

الدكتور/ عبدالمحسن الحماد , استاذ مشارك

علي سعيد القحطاني , طالب دراسات عليا

المرفقات : استفتاء

الظهران ٣١٢٦١ • المملكة العربية السعودية • تلفون : ٨٦٠-٣٢٧٩ (٠٣) • فاكس : ٨٦٠-٤٤٥٣ (٠٣) • تلكس : ٨٠١٩٥٠ جانهد • برقيا : الجامعة
Telex: 801060 KFUPM S.J. • Cable: AL-JAMAAH

تعليمات تعبئة الأستفتاء :

١- اكتب اجابة السؤال في الفراغ المخصص لذلك بالنسبة للأسئله رقم ١ و٢ و٣.
٢- اختار الأجابه من ضمن الأجوبه المدرجه للأسئله المتبقيه وذلك بوضع علامة ☑ للأجابه التي تمثل رائيك .
٣ - في حالة وجود اجابه لديك تختلف عن الأختيارات المدرجه , ارجو كتابة اجابتك بجوار السؤال أو في صفحة الملاحظات .
٤- الرجاء عدم كتابة اسمك على الأستفتاء.

اسم المبنى : ________ رقم الدور: ______ تأريخ تعبئة الأستفتاء: ______ الوقت: ____

١- العمر: __________ ٢- الوظيفه : __________ ٣- الجنسيه : ________

٤- هل تعاني من مرض مزمن ؟
☐ لا
☐ نعم

٥- هل تتعاطى اي ادويه من فتره طويله ؟
☐ لا
☐ نعم

٦- منذ متى وانت تعمل في هذا المكان ؟
☐ اقل من شهر
☐ ٢-٦ اشهر
☐ اكثر من سنه

٧- كم ساعه تقضي يوميا في هذا المكتب ؟
☐ ساعة او اقل
☐ ٢-٤ ساعات
☐ ٦-٨ ساعات

٨- كيف تقيم انتاجيتك منذ ان بدات تعمل في هذا المبنى ؟
☐ لم تتغير عن السابق
☐ افضل من السابق
☐ اسواء من السابق

٩- هل تدخن ؟ ☐ لا ☐ نعم

١٠- هل تشعر بلارتياح عند مغادرة المبنى ؟
☐ لا
☐ نعم

١١- ماهو تقييمك لدرجة الحراره في هذا المكتب ؟
☐ بارد جدا ☐ بارد
☐ بارد قليلا ☐ معتدل
☐ دافيء ☐ حار
☐ شديد الحراره

١٢- ماهو تقييمك لرطوبة الهواء في مكتبك ؟

- ☐ جاف جدا
- ☐ جاف
- ☐ معتدل
- ☐ رطب
- ☐ رطب جدا

١٣- ماهو تقييمك لصفاء الهواء في مكتبك ؟

- ☐ صافي
- ☐ يلاحظ وجود غبار
- ☐ يلاحظ وجود دخان

١٤- ماهو تقييمك لحركة الهواء من حولك ؟

- ☐ لايتحرك
- ☐ تحرك خفيف
- ☐ تيار قوي

١٥- في اي موقع من جسمك تحس بحركة الهواء؟

- ☐ الوجه
- ☐ خلف الرقبه
- ☐ اليدين
- ☐ الأرجل

١٦- ماهو تقييمك لوجود الروائح في مكتبك ؟

- ☐ لاتوجد
- ☐ خفيفه
- ☐ متوسطه
- ☐ قويه
- ☐ قويه جدا
- ☐ نفاذه

١٧- ماهو مصدر هذه الروائح في رائيك ؟

- ☐ جسم الأنسان
- ☐ دورة المياه
- ☐ اطعمه
- ☐ سجائر
- ☐ عادم سيارات
- ☐ اثاث المكتب
- ☐ اتربه او غبار

١٨- هل يوجد نوافذ في مكتبك ؟

- ☐ نعم
- ☐ لا

١٩- ماهو اتجاه النوافذ (ان وجدت) ؟

- ☐ شماليه
- ☐ شرقيه
- ☐ جنوبيه
- ☐ غربيه
- ☐ شماليه شرقيه
- ☐ شماليه غربيه
- ☐ جنوبيه شرقيه
- ☐ جنوبيه غربيه

٢٠- هل من الممكن فتح هذه النوافذ ؟ ☐ نعم
☐لا

٢١- هل تفتح النوافذ في مكتبك ؟
☐ لا افتحها ابدا ☐ بعض الأحيان
☐ نادر ☐ غالبا

٢٢- كيف تقم مستوى الضوضاء المحيط بك ؟ ☐ هدوء تام
☐ هدوء مرضي
☐ ازعاج خفيف
☐ ازعاج شديد

٢٣- كيف تقيم مستوى الأضائه من حولك ؟ ☐ اضاءه خافته
☐اضاءه معتدله
☐اضاءه شديده

٢٤- هل تلاحظ تراكم الغبار على اثاث المكتب ؟

☐ قليل جدا (يحتاج الي تنظيف مره واحده اسبوعيا)
☐ قليل (يحتاج الي تنظيف مرتين اسبوعيا)
☐ متوسط (يحتاج الي تنظيف ثلاث مرات اسبوعيا)
☐ كثير جدا (يحتاج الي تنظيف يوميا)

٢٥- هل سبق ان احسست بأي من اللأعراض المدرجه امناه خلال وجودك في هذا المكتب؟

صداع	☐ ابدا ☐ نادرا ☐ احيانا ☐ غالبا
ثقل في الراس	☐ ابدا ☐ نادرا ☐ احيانا ☐ غالبا
حرقان في العيون	☐ ابدا ☐ نادرا ☐ احيانا ☐ غالبا
حكه في الأنف	☐ ابدا ☐ نادرا ☐ احيانا ☐ غالبا
التهاب في الحلق	☐ ابدا ☐ نادرا ☐ احيانا ☐ غالبا
جفاف الفم	☐ ابدا ☐ نادرا ☐ احيانا ☐ غالبا
قصر في التنفس	☐ ابدا ☐ نادرا ☐ احيانا ☐ غالبا
الام في الصدر	☐ ابدا ☐ نادرا ☐ احيانا ☐ غالبا
غثيان	☐ ابدا ☐ نادرا ☐ احيانا ☐ غالبا
تعب عام	☐ ابدا ☐ نادرا ☐ احيانا ☐ غالبا
دوخه	☐ ابدا ☐ نادرا ☐ احيانا ☐ غالبا
عدم القدره على التركيز	☐ ابدا ☐ نادرا ☐ احيانا ☐ غالبا
جفاف الجلد	☐ ابدا ☐ نادرا ☐ احيانا ☐ غالبا

٢٤- هل تسببت تلك الأعراض في انخفاض انتاجيتك في العمل

☐ ابدا ☐ نادرا ☐ احيانا ☐ غالبا

٢٥- هل كانت تلك الأعراض سببا في خروجك مبكرا من العمل او الغياب عن العمل

☐ ابدا ☐ نادرا ☐ احيانا ☐ غالبا

٢٤- اختار احدى الجمل المدرجه ادناه والتي ترى انها صحيحه ؟

☐ المكتب مريح بشكل عام

☐ المكتب مريح لو تمت بعض التعديلات (ارجو ادراج التعديلات المقترحه في صفحة الملاحظات)

☐ المكتب غير مريح وارغب الأنتقال الى مكتب اخر(ارجو ادراج الأسباب صفحة الملاحظات)

ملاحظات :

Occupant's Questionnaire (English)

بسم الله الرحمن الرحيم

Ministry of Higher Education

King Fahd University of Petroleum & Minerals

College of Environmental Design

Architectural Engineering Program

وزارة التعليم العالي

جامعة الملك فهد للبترول و المعادن

كلية تصاميم البيئة

برنامج الهندسة المعمارية

Subject : INDOOR AIR QUALITY STUDY (MASTER THESIS)

Dear office user:

The Architectural Engineering Department at King Fahd University of Petroleum and Minerals is conducting a study through a master thesis in the area of Indoor Air Quality (IAQ). The objective of this study is to assess the indoor air quality in office buildings based on building systems evaluation and occupant's response to the indoor environment.

We would like to ask you to help us in evaluating the indoor environment in your office by filling the attached questionnaire. The collected information through this questionnaire will be the back bone of the study, so your participation is very important and will be highly appreciated. Please understand that the individualized information supplied by you will be held in the strictest confidence.

If you need any further information, please contact Ali Al-Qahtany on 8429545 or Dr. Abdulmohseen Al-Hammad on 8603581.

Sincerely yours,

Abdul-Muhsen 15/2/93

Dr. Abdulmohssen Al-Hammad, Associate Professor

Ali Al-Qahtani

Ali Al-Qahtany, Graduate Student

Encl. : Questionnaire

الظهران ٣١٢٦١ • المملكة العربية السعودية • تلفون : ٨٦٠-٣٢٧٩ (٠٣) • فاكس : ٨٦٠-٤٤٥٣ (٠٣) • تلكس : ٨٠١٩٥٠ جافهد • برقياً : الجامعة

DHAHRAN 31261, SAUDI ARABIA • Telephone : (03) 860-3279 • Fax : (03) 860-4453 • Telex : 801060 KFUPM SJ • Cable : AL-JAMAAH

How to fill this questionnaire:

1- Write your answer in the space left blank for questions 1,2, and 3
2- Check one of the multiple choice answers provided for the remaining questions ☑
3- If you have deferent answers than those provided, please write it down beside the question or in the additional comment's page.
4- Please **don't** write your name on any part of this questionnaire

Building Name : __________ Floor No. :_____ Date: / / 1993	
Time: ______	

1-How old are you? __________

2-What is your occupation? __________

3-What is your nationality? __________

4-Do you have any kind of long term illness?
- ☐ Yes
- ☐ No

5-Do you take any kind of long term medication?
- ☐ Yes
- ☐ No

6-How long have you been working in this space?
- ☐ 1month or less
- ☐ 2-6 months
- ☐ 6-12 months
- ☐ More than 1 year

7-How many hours do you spend in this space?
- ☐ 1hour or less
- ☐ 2-4 hours
- ☐ 4-6 hours
- ☐ 6-8 hours

8-How do you rate your productivity after working in this building?
- ☐ Same as before
- ☐ Better
- ☐ Worse

9-Do you smoke ?

- ❑ Yes
- ❑ No

10-Do you feel relieved when leaving the building?

- ❑ Yes
- ❑ No

11-Does the room temperature seem:

- ❑ cold
- ❑ cool
- ❑ Slightly cool
- ❑ Neutral
- ❑ Slightly warm
- ❑ Warm
- ❑ Hot

12-Does the air seem :

- ❑ Very dry
- ❑ Dry
- ❑ Normal
- ❑ Humid
- ❑ Very humid

13- How do you rate air clearity ?

- ❑ Clear
- ❑ Dusty
- ❑ Smoky

14-How do you rate the air movement?

- ❑ Still air
- ❑ little movement
- ❑ Drafty

15-Where do you usually sense air movement?

- ❑ Face
- ❑ Back of the neck
- ❑ Hands
- ❑ Feet

16-How strong is the odor in this room?

- ❑ No odor
- ❑ Slight odor
- ❑ Moderate odor
- ❑ Strong odor
- ❑ Very strong odor
- ❑ Overpowering odor

17-In your opinion, the odor in this space is mostly:

- ☐ Body odor
- ☐ Toilet odor
- ☐ Food smells
- ☐ Cigarette smells
- ☐ Car exhaust
- ☐ Furniture smells
- ☐ Dust smells

18- Are there any kind of windows in your office?

- ☐ Yes
- ☐ No

19- If Question 17 is yes, please check windows orientation(s):

☐ North ☐Northeast
☐ East ☐Northwest
☐South ☐South east
☐West ☐South west

20- If question 17 is yes, Is it possible to open the windows?

- ☐Yes
- ☐ No

21- How often do you open the windows?

☐ Never ☐ Seldom ☐ Sometimes ☐ Often

22- How do you rate the noise level in your office

☐ Very quite ☐ Moderately Quite
☐ Noisy ☐ Very Noisy

23- How do you rate the light level in your office:

☐ Low Lighting level ☐ Satisfactory ☐ Intense Lighting

24- Do you notice dust particles accumlited on the offce furnture?

- ☐ very little quantities of dust (needs once a week cleaning)
- ☐ Little quantities of dust (needs two times a week cleaning)
- ☐ Moderate quantities (needs three times a week cleaning)
- ☐ Too much dust (needs cleaning every day)

25-Have you Experienced any of the following symptoms while working in this space?

Headache	❑ Never	❑ Seldom	❑ Sometimes	❑ Often
Heavy head	❑ Never	❑ Seldom	❑ Sometimes	❑ Often
Eye Irritation	❑ Never	❑ Seldom	❑ Sometimes	❑ Often
Nose Irritation	❑ Never	❑ Seldom	❑ Sometimes	❑ Often
Throat Irritation	❑ Never	❑ Seldom	❑ Sometimes	❑ Often
Dry mouth	❑ Never	❑ Seldom	❑ Sometimes	❑ Often
Shortness of breath	❑ Never	❑ Seldom	❑ Sometimes	❑ Often
Chest pains	❑ Never	❑ Seldom	❑ Sometimes	❑ Often
Nausea	❑ Never	❑ Seldom	❑ Sometimes	❑ Often
Fatigue	❑ Never	❑ Seldom	❑ Sometimes	❑ Often
Drowsiness	❑ Never	❑ Seldom	❑ Sometimes	❑ Often
Difficulty Concentration	❑ Never	❑ Seldom	❑ Sometimes	❑ Often
Dry skin	❑ Never	❑ Seldom	❑ Sometimes	❑ Often

26- Did any of the symptoms above reduce your ability to work?
❑ Never ❑ Seldom ❑ Sometimes ❑ Often

27- Did any of the symptoms above cause you to leave work early or stay at home? ❑ Never ❑ Seldom ❑ Sometimes ❑ Often

28- Check any one of the boxes below if you agree with its statement:

- ❑ This room is comfortable in general
- ❑ This room is comfortable if some changes take place (*Please mention your suggestions of changes in the room in the additional comments in the next page)*
- ❑ This room is not comfortable and you wish to move to other office *(please indicate the reasons behind that in the additional comments in the next page)*

Additional Comments:

Building's Questionnaire

بسم الله الرحمن الرحيم

وزارة التعليم العالي
جامعة الملك فهد للبترول و المعادن
كلية تصاميم البيئة
برنامج الهندسة المعمارية

Ministry of Higher Education
King Fahd University of Petroleum & Minerals
College of Environmental Design
Architectural Engineering Program

Subject : INDOOR AIR QUALITY STUDY (MASTER THESIS)

Dear Building owner/manager :

The Architectural Engineering Department at King Fahd University of Petroleum and Minerals is conducting a study through a master thesis in the area of Indoor Air Quality (IAQ). The objective of this study is to assess the indoor air quality in office buildings based on building systems evaluation and occupant's response to the indoor environment.

Having seen your building construction quality, we think it will be a good candidate for the study survey. Therefore, we would like you to help us by filling the questionnaire about your building systems. Also we would like your assistant in distributing occupant's questionnaire to seek their evaluation of the indoor environment. The collected information through these questionnaires will be the back bone of the study, so your participation is very important and will be highly appreciated. Please understand that individualized information supplied in any of these questionnaires will be held in the strictest confidence. However, we will be very glad to share our summarized statistical result of the survey with you.

If you need any further information, please contact Ali Al-Qahtany on 8429545 or Dr. Abdulmohseen Al-Hammad on 8603581.

Sincerely yours,

Abdul-Mohsen 15/2/93

Dr. Abdulmohssen Al-Hammad, Associate Professor

Ali Al-Qahtani

Ali Al-Qahtany, Graduate Student

Encl. : Building Manager Questionnaire
Occupants Questionnaire copies

الظهران ٣١٢٦١ • المملكة العربية السعودية • تلفون : ٨٦٠-٢٢٧٩ (٠٣) • فاكس : ٨٦٠-٤٤٥٣ (٠٣) • تلكس : ٨٠١٩٥٠ جامعة • برقيا : الجامعة
... KFUPM SJ • Cable : AL-JAMAAH

Building Name :_______________	Building Number :_________
Date : / / 1993	Time: ____

1 General Operation & Maintenance Information:

1.1- How old is this building ? __________

1.2- Building Operation & Maintenance is performed by:
- ❑ Your own O&M personal ❑ One Prime contractor for all building systems
- ❑ Several specialized contractors ❑ On call contractor

1.3- The pattern of Building Maintenance is :
- ❑ All corrective maintenance ❑ 20 % corrective & 80% preventive
- ❑ 50% Corrective & 50% Preventive ❑ 70% corrective & 30% Preventive
- ❑ Others:_______________________________

1.4- How often do you shampoo carpets ?
- ❑ Only when requested ❑ Once a month
- ❑ twice a month ❑ Others :_______

1.5- How often do you clean floor (non carpeted areas)?
- ❑ Daily ❑ Every other day ❑ Once a week Others : _______

1.6- Operation and maintenance manuals are :
- ❑ Available ❑ Partially available ❑ Not available

1.7- As built drawings are :
- ❑ Available ❑ Partially available ❑ Not available

1.8- Do you use any kind of pesticides for Pest Control in your building?
- ❑No ❑ Yes

1.9- When do you apply Pest Control?(If 1.8 is Yes)
- ❑Only when Pest problems occur ❑ Regularly as per yearly Pest Control schedule(Please state how often in the space below)

____

____

____

2.HVAC System Information:

2.1- What kind of HVAC system(s) serving this building ?
- ❑ Chilled water fan coil units ❑ Dx fan coil units ❑ VAV system ❑ Reheat
- ❑ Single zone system ❑ Multi- zone system ❑ Dual duct system
- ❑ Others :____________________

2.2- What kind of Ducting material is used ?
- ❑ Galvanized steel ducting ❑ Fiberglass ducting ❑ stain steel ducting
- ❑ Others:____________________

2.3- What kind of air filter are used in HVAC system ?
- ❑ Panel Grease Extended Surface ❑ Panel Dry Extended Surface
- ❑ Moving Curtain Grease ❑ Moving Curtain Dry-Media
- ❑ Electronic Air Cleaners ❑ Others:____________________

2.4- Is your HVAC system(s) equipped with Economizer cycle ?
- ❑ No ❑ Yes

2.5- What is the fresh air supply rates by the HVAC system?
- ❑ 5 CFM/person ❑ 10 CFM/Person ❑ 15 CFM/person ❑ 20 CFM/Person
- ❑ Others:____________________

2.6- Have you perform any HVAC system calibration and balancing since the occupation date?
- ❑ None ❑ Once ❑ Twice ❑ Three times ❑ Only after major renovation

2.7- Have you performed any kind of duct cleaning since the occupation date ?
- ❑ None ❑ Once ❑ Twice ❑ Three times

2.8- How often do you perform Preventive Maintenance for HVAC system?
- ❑ None (rely only on corrective maintenance) ❑ Once a year ❑ Twice a year
- ❑ Three times a year ❑ Four times a year

2.9- What are the Operational modes of the HVAC systems in this building ?
- ❑ System is operated 24 hr's ❑ System is operated during office hours only
- ❑ System is operated 2 hr's earlier than occupancy time ❑ Others:__________

2.10- Where are the refrigeration equipment of the HVAC system located?
- ❑ On the roof of the building ❑ Outdoor mechanical space
- ❑ Indoor Mechanical rooms

2.11- The return air is conveyed by: ❑ Return air ducting ❑ Return air plenum

2.12- Is the HVAC system equipped with Humidifier(s): ❑Yes ❑No

3.Architectural Systems:

3.1- How many floors are in this buildings ? :_______

3.2- How many of these floor are :(please indicate the number of floor beside each class)

Office building :_______ Commercial :_______ Residential :_______

Others :______

3.3- How many offices are there in each floor ? __________________

3.4- What is occupants population in this building?_________________

3.5- Do you have car parking garage within this building ? ❑ NO ❑ Yes

3.6- Do you have loading dock(s) in this building? ❑ NO ❑ Yes

3.7- What type of office layout is commonly used in this building?

❑ Flexible layout (open plane offices) ❑ Fixed layout (predetermined office layout by original design)

3.8- Copy machines in use in this building are:

❑ located in copy machine rooms only ❑ Scattered in many locations

3.9- Do you have smoking lounge(s) ? ❑ NO ❑ Yes

3.10- What kind of fixing method(s) do you use with floor carpeting?

❑ Glue ❑ Adhesive tape ❑ Mechanical Fasteners ❑ Others__________

3.11- What is the percentage of wall paper on the interior walls of the buildings?

0 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

|____|____|____|____|____|____|____|____|____|____|

No wall paper — All walls has wall paper

3.12- What is the percentage of wood paneling on wall of this building?

0 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

|____|____|____|____|____|____|____|____|____|____|

No wood panels — All walls has wood panels

3.13- What is the percentage of carpeted floor in this building ?

0 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

|____|____|____|____|____|____|____|____|____|____|

No carpet — All floors are carpeted

3.14- The Building exterior envelop is:

❑ Concrete ❑ Curtain wall ❑ Double CMU with insulation in between
❑ Precast concrete with impeded thermal insulation ❑ CMU with interior thermal insulation ❑ CMU with exterior thermal insulation ❑ Glass envelop
❑ Others :______________________________

3.15- What type of furniture is commonly used in this building ? (if more that one type is commonly used please check the desired boxes and indicate the approximate percentage of each in the space beside each type)

❑ Hard wood furniture ___
❑ Particleboard furniture ___
❑ Metal furniture ____
❑ Synthetic resins furniture (fiberglass or plastic furniture)____

4.Indoor Environment:

4.1-Have you received any complaints about the indoor environment from building occupants about :

4.1.1-Room temperature ❑ Never ❑ Seldom ❑ Sometimes ❑ Often

4.1.2-Humidity ❑ Never ❑ Seldom ❑ Sometimes ❑ Often

4.1.3-Air Movement ❑ Never ❑ Seldom ❑ Sometimes ❑ Often

4.1.4-Odors ❑ Never ❑ Seldom ❑ Sometimes ❑ Often

4.1.5-Light ❑ Never ❑ Seldom ❑ Sometimes ❑ Often

4.1.6-Noise ❑ Never ❑ Seldom ❑ Sometimes ❑ Often

4.2- Did you receive any health related complaints from occupants resulted from indoor environment?

❑ No ❑ Yes

(if yes please indicate what kind of complaint was it)

____
____
____
____

Appendix C : Statistical Analysis Output

-- Correlation Coefficients --

	SYMINDX	CLEARITY	DUST	ODOR	SOURCE
SYMINDX	1.0000	.2563	.2966	.3872	.1957
	(846)	(835)	(839)	(831)	(649)
	P= .	P= .000	P= .000	P= .000	P= .000
CLEARITY	.2563	1.0000	.2635	.4203	.1635
	(835)	(835)	(828)	(821)	(641)
	P= .000	P= .	P= .000	P= .000	P= .000
DUST	.2966	.2635	1.0000	.2829	.2072
	(839)	(828)	(839)	(826)	(645)
	P= .000	P= .000	P= .	P= .000	P= .000
ODOR	.3872	.4203	.2829	1.0000	.0742
	(831)	(821)	(826)	(831)	(643)
	P= .000	P= .000	P= .000	P= .	P= .060
SOURCE	.1957	.1635	.2072	.0742	1.0000
	(649)	(641)	(645)	(643)	(649)
	P= .000	P= .000	P= .000	P= .060	P= .

(Coefficient / (Cases) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed

- - Correlation Coefficients - -

	SYMINDX	LIGHT	NOISE
SYMINDX	1.0000	-.1156	.2317
	(846)	(843)	(835)
	P= .	P= .001	P= .000
LIGHT	-.1156	1.0000	-.1027
	(843)	(843)	(834)
	P= .001	P= .	P= .003
NOISE	.2317	-.1027	1.0000
	(835)	(834)	(835)
	P= .000	P= .003	P= .

(Coefficient / (Cases) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed

- - Correlation Coefficients - -

	SYMINDX	AGE	JOB	COUNTRY	ILLNESS	MED
SYMINDX	1.0000	-.0771	-.0121	-.0430	-.0626	-.0733
	(846)	(820)	(805)	(822)	(844)	(843)
	P= .	P= .027	P= .732	P= .219	P= .069	P= .033
AGE	-.0771	1.0000	.2183	.2127	-.0304	-.0231
	(820)	(820)	(799)	(816)	(818)	(817)
	P= .027	P= .	P= .000	P= .000	P= .385	P= .509
JOB	-.0121	.2183	1.0000	.1419	-.0128	-.0166
	(805)	(799)	(805)	(800)	(803)	(802)
	P= .732	P= .000	P= .	P= .000	P= .718	P= .638
COUNTRY	-.0430	.2127	.1419	1.0000	.0629	.0344
	(822)	(816)	(800)	(822)	(820)	(819)
	P= .219	P= .000	P= .000	P= .	P= .072	P= .326
ILLNESS	-.0626	-.0304	-.0128	.0629	1.0000	.6932
	(844)	(818)	(803)	(820)	(844)	(842)
	P= .069	P= .385	P= .718	P= .072	P= .	P= .000
MED	-.0733	-.0231	-.0166	.0344	.6932	1.0000
	(843)	(817)	(802)	(819)	(842)	(843)
	P= .033	P= .509	P= .638	P= .326	P= .000	P= .
HOURS	.0800	.0329	-.0265	.0099	-.0212	-.1170
	(844)	(818)	(804)	(820)	(842)	(841)
	P= .020	P= .347	P= .453	P= .778	P= .539	P= .001
MONTHS	.0660	.0023	.1113	-.1319	-.0161	-.0048
	(844)	(819)	(804)	(821)	(842)	(841)
	P= .055	P= .947	P= .002	P= .000	P= .641	P= .889
SMOKING	-.0251	.0657	.0497	.0115	.1099	.0937
	(843)	(817)	(802)	(819)	(841)	(840)
	P= .466	P= .060	P= .159	P= .742	P= .001	P= .007

(Coefficient / (Cases) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed

-- Correlation Coefficients --

	SYMINDX	TEMP	HUMID	WINORINT
SYMINDX	1.0000	.0899	-.0818	.0485
	(846)	(838)	(843)	(623)
	P= .	P= .009	P= .018	P= .227
TEMP	.0899	1.0000	.0369	.0543
	(838)	(838)	(837)	(616)
	P= .009	P= .	P= .287	P= .178
HUMID	-.0818	.0369	1.0000	-.0217
	(843)	(837)	(843)	(621)
	P= .018	P= .287	P= .	P= .590
WINORINT	.0485	.0543	-.0217	1.0000
	(623)	(616)	(621)	(623)
	P= .227	P= .178	P= .590	P= .

(Coefficient / (Cases) / 2-tailed Significance)

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- - Correlation Coefficients - -

	MOVMENT	SENSE	RELIEVED	SYMINDX	LEAVWORK	ABILITY
MOVMENT	1.0000 (834) P= .	.0009 (693) P= .981	-.0156 (788) P= .663	.0054 (834) P= .877	.0152 (804) P= .667	-.0156 (804) P= .659
SENSE	.0009 (693) P= .981	1.0000 (699) P= .	-.1178 (672) P= .002	.0150 (699) P= .693	.0082 (676) P= .832	-.0265 (673) P= .493
RELIEVED	-.0156 (788) P= .663	-.1178 (672) P= .002	1.0000 (798) P= .	-.1756 (798) P= .000	-.0699 (771) P= .052	-.1140 (771) P= .002
SYMINDX	.0054 (834) P= .877	.0150 (699) P= .693	-.1756 (798) P= .000	1.0000 (846) P= .	.3681 (816) P= .000	.4958 (816) P= .000
LEAVWORK	.0152 (804) P= .667	.0082 (676) P= .832	-.0699 (771) P= .052	.3681 (816) P= .000	1.0000 (816) P= .	.5311 (811) P= .000
ABILITY	-.0156 (804) P= .659	-.0265 (673) P= .493	-.1140 (771) P= .002	.4958 (816) P= .000	.5311 (811) P= .000	1.0000 (816) P= .

(Coefficient / (Cases) / 2-tailed Significance)

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- - Correlation Coefficients - -

	BULDGAGE	OM	MAINTPAT	CARPET	FLOOR	MANUALS
BULDGAGE	1.0000	.1154	-.1704	.0619	.1242	.0890
	(30)	(30)	(30)	(26)	(30)	(30)
	P= .	P= .544	P= .368	P= .764	P= .513	P= .640
OM	.1154	1.0000	.0806	-.1435	-.0412	-.3349
	(30)	(30)	(30)	(26)	(30)	(30)
	P= .544	P= .	P= .672	P= .484	P= .829	P= .070
MAINTPAT	-.1704	.0806	1.0000	.3387	.1387	.1731
	(30)	(30)	(30)	(26)	(30)	(30)
	P= .368	P= .672	P= .	P= .091	P= .465	P= .360
CARPET	.0619	-.1435	.3387	1.0000	-.1126	.4192
	(26)	(26)	(26)	(26)	(26)	(26)
	P= .764	P= .484	P= .091	P= .	P= .584	P= .033
FLOOR	.1242	-.0412	.1387	-.1126	1.0000	.1138
	(30)	(30)	(30)	(26)	(30)	(30)
	P= .513	P= .829	P= .465	P= .584	P= .	P= .549
MANUALS	.0890	-.3349	.1731	.4192	.1138	1.0000
	(30)	(30)	(30)	(26)	(30)	(30)
	P= .640	P= .070	P= .360	P= .033	P= .549	P= .
DRAWINGS	-.0396	-.2578	.1588	.4192	-.0102	.7242
	(30)	(30)	(30)	(26)	(30)	(30)
	P= .836	P= .169	P= .402	P= .033	P= .957	P= .000
PCONTROL	.1557	.1248	-.0229	-.4842	-.0510	.2254
	(26)	(26)	(26)	(22)	(26)	(26)
	P= .448	P= .543	P= .912	P= .022	P= .805	P= .268
PERCENT	.1604	.2540	-.0505	-.0444	-.2500	.0936
	(30)	(30)	(30)	(26)	(30)	(30)
	P= .397	P= .176	P= .791	P= .830	P= .183	P= .623

(Coefficient / (Cases) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed

- - Correlation Coefficients - -

	DRAWINGS	PCONTROL	PERCENT
BULDGAGE	-.0396	.1557	.1604
	(30)	(26)	(30)
	P= .836	P= .448	P= .397
OM	-.2578	.1248	.2540
	(30)	(26)	(30)
	P= .169	P= .543	P= .176
MAINTPAT	.1588	-.0229	-.0505
	(30)	(26)	(30)
	P= .402	P= .912	P= .791
CARPET	.4192	-.4842	-.0444
	(26)	(22)	(26)
	P= .033	P= .022	P= .830
FLOOR	-.0102	-.0510	-.2500

	(30)	(26)	(30)
	P= .957	P= .805	P= .183
MANUALS	.7242	.2254	.0936
	(30)	(26)	(30)
	P= .000	P= .268	P= .623
DRAWINGS	1.0000	.0653	.1705
	(30)	(26)	(30)
	P= .	P= .751	P= .368
PCONTROL	.0653	1.0000	.2184
	(26)	(26)	(26)
	P= .751	P= .	P= .284
PERCENT	.1705	.2184	1.0000
	(30)	(26)	(30)
	P= .368	P= .284	P= .

(Coefficient / (Cases) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed

" . " is printed if a coefficient cannot be computed

	DUCTCLEN	HVACPM	OPERMOD	REFEQUIP	RETUAIR	HUMDFER
PERCENT	-.1129	.2933	-.1827	-.1746	-.0086	-.0419
	(28)	(29)	(30)	(29)	(28)	(28)
	P= .567	P= .122	P= .334	P= .365	P= .965	P= .832
HVACSYS	-.3246	.1368	-.0143	-.1124	-.0126	.1482
	(28)	(29)	(30)	(29)	(28)	(28)
	P= .092	P= .479	P= .940	P= .562	P= .949	P= .452
DUCTS	.5260	.1878	-.0702	-.1678	.3235	.1516
	(28)	(29)	(30)	(29)	(28)	(28)
	P= .004	P= .329	P= .712	P= .384	P= .093	P= .441
FILTERS	-.0744	.1233	.4278	-.0062	-.2813	-.7032
	(27)	(27)	(28)	(28)	(27)	(27)
	P= .712	P= .540	P= .023	P= .975	P= .155	P= .000
CYCLE	-.5839	-.2951	.1508	.1092	-.2796	-.0667
	(28)	(29)	(30)	(29)	(28)	(28)
	P= .001	P= .120	P= .426	P= .573	P= .150	P= .736
TESTING	.4079	.1664	-.1838	-.2643	-.1781	-.3189
	(28)	(29)	(30)	(29)	(28)	(28)
	P= .031	P= .388	P= .331	P= .166	P= .365	P= .098
DUCTCLEN	1.0000	.3690	-.1699	-.2704	.2416	-.1208
	(28)	(28)	(28)	(28)	(27)	(27)
	P= .	P= .053	P= .387	P= .164	P= .225	P= .548
HVACPM	.3690	1.0000	-.1096	-.4138	-.0380	-.2088
	(28)	(29)	(29)	(28)	(27)	(27)
	P= .053	P= .	P= .571	P= .029	P= .851	P= .296

(Coefficient / (Cases) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed

- - Correlation Coefficients - -

	DUCTCLEN	HVACPM	OPERMOD	REFEQUIP	RETUAIR	HUMDFER
OPERMOD	-.1699	-.1096	1.0000	-.0383	-.1536	-.2320
	(28)	(29)	(30)	(29)	(28)	(28)
	P= .387	P= .571	P= .	P= .844	P= .435	P= .235
REFEQUIP	-.2704	-.4138	-.0383	1.0000	.2684	.0774
	(28)	(28)	(29)	(29)	(28)	(28)
	P= .164	P= .029	P= .844	P= .	P= .167	P= .695
RETUAIR	.2416	-.0380	-.1536	.2684	1.0000	.2384
	(27)	(27)	(28)	(28)	(28)	(28)
	P= .225	P= .851	P= .435	P= .167	P= .	P= .222
HUMDFER	-.1208	-.2088	-.2320	.0774	.2384	1.0000
	(27)	(27)	(28)	(28)	(28)	(28)
	P= .548	P= .296	P= .235	P= .695	P= .222	P= .

(Coefficient / (Cases) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed

- - Correlation Coefficients - -

	PERCENT	HVACSYS	DUCTS	FILTERS	CYCLE	TESTING
PERCENT	1.0000 (30) P= .	.4568 (30) P= .011	.0656 (30) P= .730	.0171 (28) P= .931	.0604 (30) P= .751	-.1496 (30) P= .430
HVACSYS	.4568 (30) P= .011	1.0000 (30) P= .	-.0497 (30) P= .794	-.0600 (28) P= .762	.2400 (30) P= .201	-.2207 (30) P= .241
DUCTS	.0656 (30) P= .730	-.0497 (30) P= .794	1.0000 (30) P= .	-.2278 (28) P= .244	-.2873 (30) P= .124	.1381 (30) P= .467
FILTERS	.0171 (28) P= .931	-.0600 (28) P= .762	-.2278 (28) P= .244	1.0000 (28) P= .	.0301 (28) P= .879	.0213 (28) P= .914
CYCLE	.0604 (30) P= .751	.2400 (30) P= .201	-.2873 (30) P= .124	.0301 (28) P= .879	1.0000 (30) P= .	-.1785 (30) P= .345
TESTING	-.1496 (30) P= .430	-.2207 (30) P= .241	.1381 (30) P= .467	.0213 (28) P= .914	-.1785 (30) P= .345	1.0000 (30) P= .
DUCTCLEN	-.1129 (28) P= .567	-.3246 (28) P= .092	.5260 (28) P= .004	-.0744 (27) P= .712	-.5839 (28) P= .001	.4079 (28) P= .031
HVACPM	.2933 (29) P= .122	.1368 (29) P= .479	.1878 (29) P= .329	.1233 (27) P= .540	-.2951 (29) P= .120	.1664 (29) P= .388
OPERMOD	-.1827 (30) P= .334	-.0143 (30) P= .940	-.0702 (30) P= .712	.4278 (28) P= .023	.1508 (30) P= .426	-.1838 (30) P= .331
REFEQUIP	-.1746 (29) P= .365	-.1124 (29) P= .562	-.1678 (29) P= .384	-.0062 (28) P= .975	.1092 (29) P= .573	-.2643 (29) P= .166
RETUAIR	-.0086 (28) P= .965	-.0126 (28) P= .949	.3235 (28) P= .093	-.2813 (27) P= .155	-.2796 (28) P= .150	-.1781 (28) P= .365

(Coefficient / (Cases) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed

- - Correlation Coefficients - -

	PERCENT	HVACSYS	DUCTS	FILTERS	CYCLE	TESTING
HUMDFER	-.0419 (28) P= .832	.1482 (28) P= .452	.1516 (28) P= .441	-.7032 (27) P= .000	-.0667 (28) P= .736	-.3189 (28) P= .098

(Coefficient / (Cases) / 2-tailed Significance)

- - Correlation Coefficients - -

	NOFLOOR	GARAGE	DOCK	OFFICLAY	COPYMACH	LOUNG
NOFLOOR	1.0000	-.0433	-.6002	-.1817	.0731	.1247
	(30)	(30)	(29)	(29)	(28)	(30)
	P= .	P= .820	P= .001	P= .346	P= .711	P= .511
GARAGE	-.0433	1.0000	.2090	.4046	-.0231	-.1287
	(30)	(30)	(29)	(29)	(28)	(30)
	P= .820	P= .	P= .277	P= .029	P= .907	P= .498
DOCK	-.6002	.2090	1.0000	.1682	.1742	.0573
	(29)	(29)	(29)	(28)	(27)	(29)
	P= .001	P= .277	P= .	P= .392	P= .385	P= .768
OFFICLAY	-.1817	.4046	.1682	1.0000	-.0621	-.2354
	(29)	(29)	(28)	(29)	(27)	(29)
	P= .346	P= .029	P= .392	P= .	P= .758	P= .219
COPYMACH	.0731	-.0231	.1742	-.0621	1.0000	.0000
	(28)	(28)	(27)	(27)	(28)	(28)
	P= .711	P= .907	P= .385	P= .758	P= .	P=1.000
LOUNG	.1247	-.1287	.0573	-.2354	.0000	1.0000
	(30)	(30)	(29)	(29)	(28)	(30)
	P= .511	P= .498	P= .768	P= .219	P=1.000	P= .
CARPTFIX	-.2346	-.3209	.3443	-.2940	.1160	-.0038
	(29)	(29)	(28)	(29)	(27)	(29)
	P= .221	P= .090	P= .073	P= .122	P= .564	P= .984
WALLPAPR	.2402	-.1584	-.1543	-.0640	-.2333	-.0362
	(30)	(30)	(29)	(29)	(28)	(30)
	P= .201	P= .403	P= .424	P= .741	P= .232	P= .849
WOOD	-.3008	.1352	-.1082	.2645	-.2681	-.3203
	(30)	(30)	(29)	(29)	(28)	(30)
	P= .106	P= .476	P= .577	P= .166	P= .168	P= .084
CARPTARE	.1850	-.2815	.0601	-.2812	.3598	.3553
	(30)	(30)	(29)	(29)	(28)	(30)
	P= .328	P= .132	P= .757	P= .139	P= .060	P= .054
ENVELOP	.3033	.0904	.0299	.0985	.2856	-.1387
	(30)	(30)	(29)	(29)	(28)	(30)
	P= .103	P= .635	P= .878	P= .611	P= .141	P= .465

(Coefficient / (Cases) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed

- - Correlation Coefficients - -

	NOFLOOR	GARAGE	DOCK	OFFICLAY	COPYMACH	LOUNG
FURNITUR	-.1281	.2594	.0000	.2309	.1482	-.0683
	(28)	(28)	(27)	(28)	(27)	(28)
	P= .516	P= .182	P=1.000	P= .237	P= .461	P= .730
PERCENT	.1396	.1809	-.0396	.0858	.1954	-.1749
	(30)	(30)	(29)	(29)	(28)	(30)
	P= .462	P= .339	P= .838	P= .658	P= .319	P= .355

(Coefficient / (Cases) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed

	CARPTFIX	WALLPAPR	WOOD	CARPTARE	ENVELOP	FURNITUR
NOFLOOR	-.2346 (29) P= .221	.2402 (30) P= .201	-.3008 (30) P= .106	.1850 (30) P= .328	.3033 (30) P= .103	-.1281 (28) P= .516
GARAGE	-.3209 (29) P= .090	-.1584 (30) P= .403	.1352 (30) P= .476	-.2815 (30) P= .132	.0904 (30) P= .635	.2594 (28) P= .182
DOCK	.3443 (28) P= .073	-.1543 (29) P= .424	-.1082 (29) P= .577	.0601 (29) P= .757	.0299 (29) P= .878	.0000 (27) P=1.000
OFFICLAY	-.2940 (29) P= .122	-.0640 (29) P= .741	.2645 (29) P= .166	-.2812 (29) P= .139	.0985 (29) P= .611	.2309 (28) P= .237
COPYMACH	.1160 (27) P= .564	-.2333 (28) P= .232	-.2681 (28) P= .168	.3598 (28) P= .060	.2856 (28) P= .141	.1482 (27) P= .461
LOUNG	-.0038 (29) P= .984	-.0362 (30) P= .849	-.3203 (30) P= .084	.3553 (30) P= .054	-.1387 (30) P= .465	-.0683 (28) P= .730
CARPTFIX	1.0000 (29) P= .	.1491 (29) P= .440	-.1986 (29) P= .302	.3532 (29) P= .060	-.0432 (29) P= .824	-.0512 (28) P= .796

(Coefficient / (Cases) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed

- - Correlation Coefficients - -

	CARPTFIX	WALLPAPR	WOOD	CARPTARE	ENVELOP	FURNITUR
WALLPAPR	.1491 (29) P= .440	1.0000 (30) P= .	-.2365 (30) P= .208	.0209 (30) P= .913	-.0968 (30) P= .611	-.3496 (28) P= .068
WOOD	-.1986 (29) P= .302	-.2365 (30) P= .208	1.0000 (30) P= .	-.7589 (30) P= .000	.1246 (30) P= .512	.1905 (28) P= .331
CARPTARE	.3532 (29) P= .060	.0209 (30) P= .913	-.7589 (30) P= .000	1.0000 (30) P= .	-.1090 (30) P= .566	.0078 (28) P= .968
ENVELOP	-.0432 (29) P= .824	-.0968 (30) P= .611	.1246 (30) P= .512	-.1090 (30) P= .566	1.0000 (30) P= .	.1291 (28) P= .513
FURNITUR	-.0512 (28) P= .796	-.3496 (28) P= .068	.1905 (28) P= .331	.0078 (28) P= .968	.1291 (28) P= .513	1.0000 (28) P= .
PERCENT	.0219 (29) P= .910	-.0242 (30) P= .899	.1192 (30) P= .530	-.0315 (30) P= .869	.5465 (30) P= .002	.2986 (28) P= .123

(Coefficient / (Cases) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed

- - Correlation Coefficients - -

	PERCENT
NOFLOOR	.1396 (30) P= .462
GARAGE	.1809 (30) P= .339
DOCK	-.0396 (29) P= .838
OFFICLAY	.0858 (29) P= .658
COPYMACH	.1954 (28) P= .319
LOUNG	-.1749 (30) P= .355
CARPTFIX	.0219 (29) P= .910
WALLPAPR	-.0242 (30) P= .899
WOOD	.1192 (30) P= .530
CARPTARE	-.0315 (30) P= .869
ENVELOP	.5465 (30) P= .002

(Coefficient / (Cases) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed

- - Correlation Coefficients - -

	PERCENT
FURNITUR	.2986 (28) P= .123

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